USGS & NASA Digital Imagery Product Characterization

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- ## USGS and NASA are jointly developing an airborne digital imagery characterization capability
    - Supports USGS future procurement and cooperative partnerships for digital imagery acquisition
    - Enables digital data providers the ability to sell products to a larger market
    - Provides NASA with access to high spatial resolution imagery for development of new characterization techniques

- ## NASA - USGS Space Act Agreement signed January 2003
    - USGS Role: Define characterization requirements, interface with industry, provide certification
    - NASA Role: Perform product characterization using Stennis test range

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- Vendors acquire data over Stennis characterization range

- Vendors provide common data package to Stennis

- Stennis personnel perform geopositional and spatial response characterization analyses
  - Radiometric characterization to be performed in the future

- Document results in report and delivery to USGS

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- The Stennis characterization range is built within the Stennis "Fee Area"
  - Approximately 5 mi. x 5 mi. in size
  - Land cover:
    - Buildings
    - Roads
    - Canals
    - Pine Forests
    - Wetlands
    - Open grass
  - Characterization Targets
    - Geodetic network
    - Concrete edge targets
    - Radiometric targets and atmospheric instrumentation

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Stennis Geodetic Targets

- Currently 45 targets located throughout Stennis Space Center (SSC) "Fee Area"

- Targets are 2.44 m in diameter painted white with a 0.6 m red center

- Target centers have been geolocated by Global Positioning System (GPS) to <3 cm accuracy
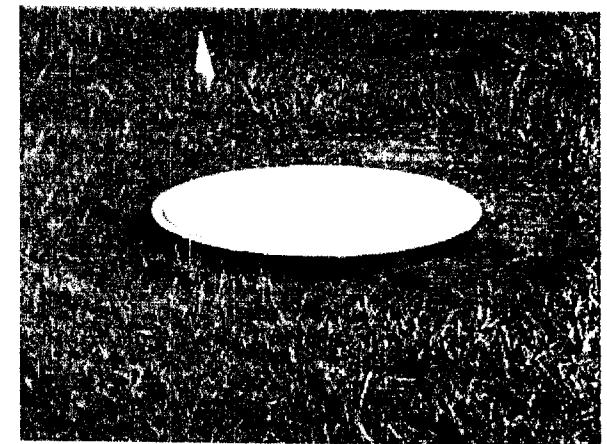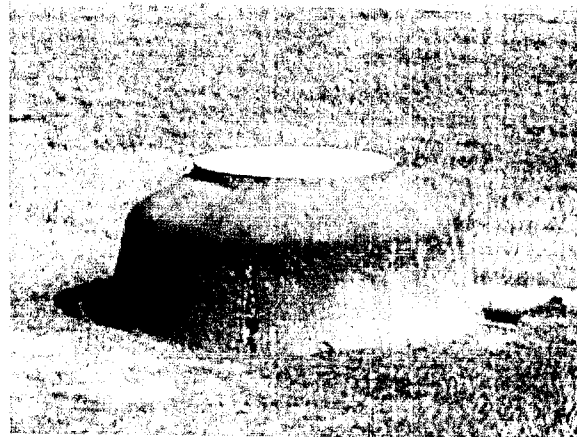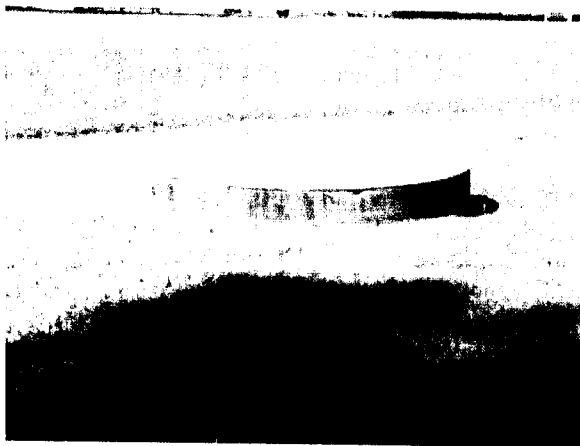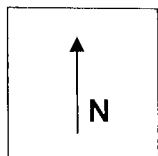
DRAFT
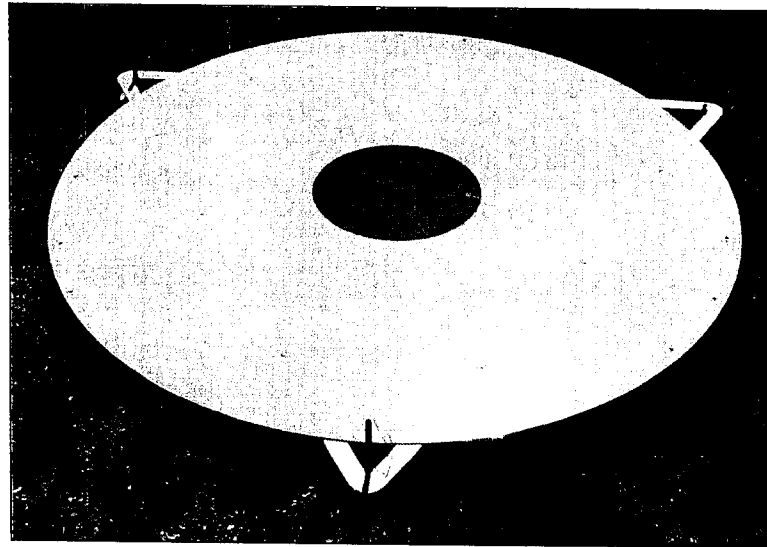
Stennis Manhole Covers

- 136 painted/surveyed man-hole covers located throughout SSC fee area

- Paint reflectance nominally 50%

- Manhole cover diameters range between 0.6 and 2.9 meters

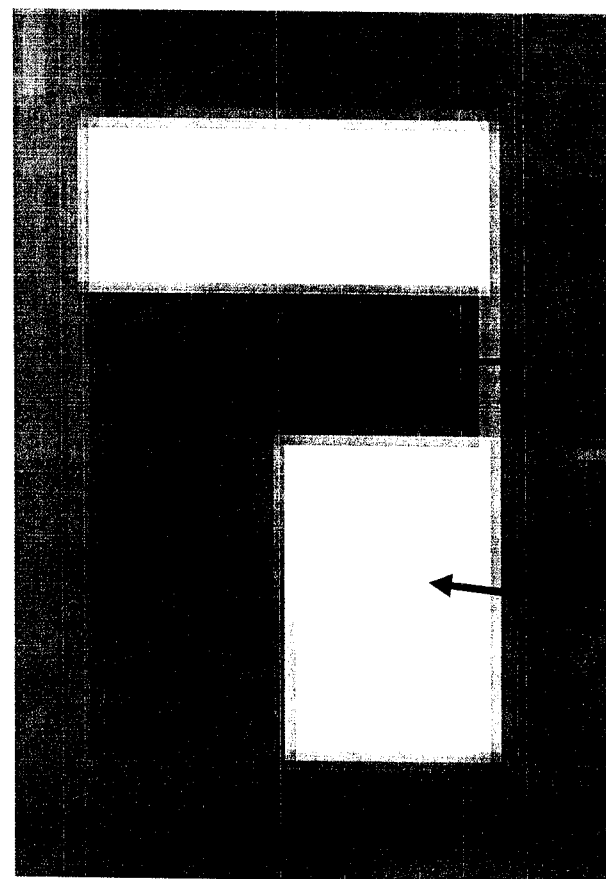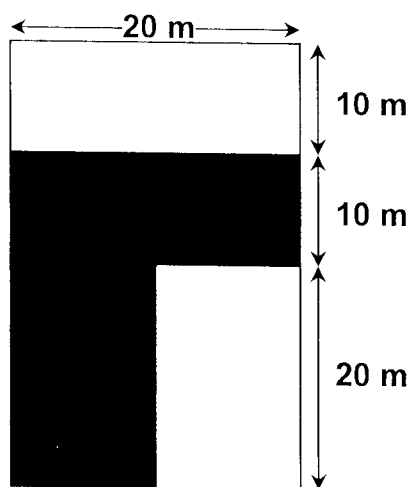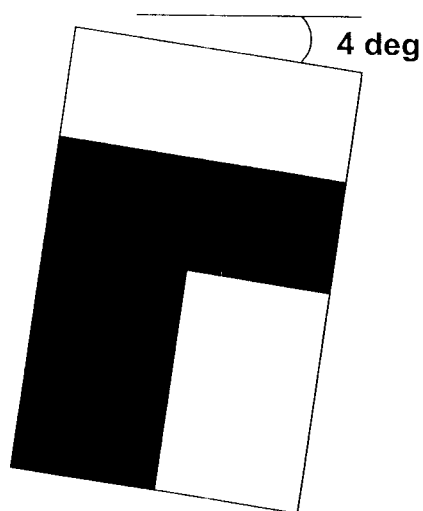- Manhole cover centers have been geolocated by GPS to <3 cm horizontal accuracy

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Stennis Edge Target

Lat/lon:
30 23 10.1N
89 37 43.6W

4 deg

20 m

10 m

10 m

20 m

~5% reflective

~50% reflective

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Stennis Characterization Site
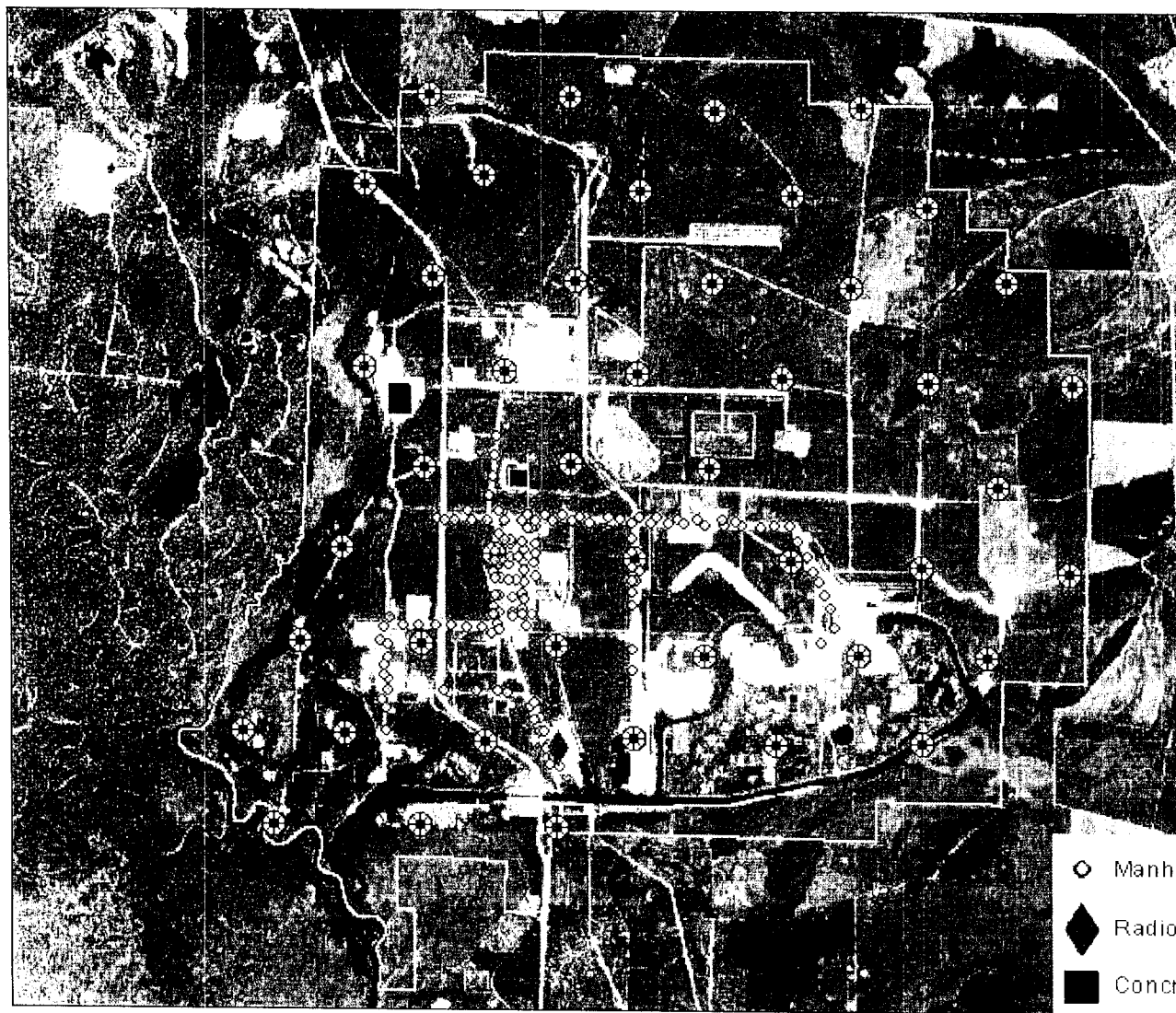
Legend:
- ○ Manhole Cover Targets
- ◆ Radiometric Targets
- ■ Concrete Edge Targets
- ⊕ Geodetic Targets
- Fee Area Line

Delivered Data

- Vendors provide common data package to Stennis
  - Panchromatic and/or multispectral (RGB) imagery
  - Smallest ground sample distance (GSD) that vendor plans to sell to USGS, and no greater than 1-meter GSD
  - Orthorectified and mosaicked imagery
  - Standard USGS National Elevation Dataset (NED) digital elevation model (DEM)
  - Uncompressed or lossless compression (TBD)
  - NAD83 datum
  - Federal Geographic Data Committee (FGDC) compliant metadata format
  - UTM Zone 16
  - Compatible with common RS software packages (IMAGINE, ENVI)
  - Ground Control
    - Five ground control point locations are provided to the vendors
    - Locations of points are approximately in each corner and the center of the Fee Area

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Other Data Considerations

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To perform spatial response assessments, delivered data products must have the following characteristics:

- **Radiometric Response**
  - Radiometric response cannot differ by more than 1% over a uniform area for pixels separated by less than 20 meters.
  - Dynamic range must be such that objects with reflectance of 5% and 50% are imaged without saturation.
- **Image Registration**
  - Images resampled using the cubic-convolution or bilinear interpolation can be used directly for spatial resolution characterization.
  - Images resampled with the nearest-neighbor method can be used only when the resampling results in a uniform shift of the entire image or when precise data on the original geolocation of each pixel is available. Otherwise, non-resampled images must be provided for the analysis.

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- EarthData Technologies
  - Acquired Leica ADS40 data in November 2002
  - Geopositional and spatial assessment completed (pending)

- Emerge
  - Acquired Digital Sensor System (DSS) data in January 2003
  - Geopositional assessment completed
  - Spatial assessment could not be performed because of data saturation over edge target

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Status (cont'd.)

- ## Northwest Geomatics
  - Acquired Leica ADS40 data in October 2003
  - Awaiting data delivery

- ## Space Imaging
  - Acquired Digital Airborne Imagery System (DAIS) data in November 2003
  - Geopositional and spatial assessments completed

- ## Aerometric
  - Acquired Zeiss DMC data in February 2004
  - Awaiting data delivery

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Geopositional Assessment Approach

- Locations of geodetic targets and manhole covers identified in the imagery are compared to "true" locations of the targets
- Positional differences are calculated from the ground truth data to the same points in the image being evaluated
- From these differences statistics are calculated

These equations may be found in FGDC standard FGDC-STD-007-3-1998

Easting Delta $= \Delta X = X_{input} - X_{control}$

Northing Delta $= \Delta Y = Y_{input} - Y_{control}$

Number of Input Targets Used for Image Characterization $= n$

$$RMSE_x = \sqrt{\sum \frac{(\Delta X)^2}{n}}$$

$$RMSE_y = \sqrt{\sum \frac{(\Delta Y)^2}{n}}$$

$$RMSE_{net} = \sqrt{RMSE_x^2 + RMSE_y^2}$$

$$CE_{90} = \frac{2.1460}{2}\left(RMSE_x + RMSE_y\right)$$

$$CE_{95} = \frac{2.4477}{2}\left(RMSE_x + RMSE_y\right)$$

Relative Edge Response (RER) is estimated using Stennis edge target and a tilted edge technique

- *RER* is one of the engineering parameters used in the General Image Quality Equation (GIQE) to provide predictions of imaging system performance expressed in terms of the National Imagery Interpretability Rating Scale (NIIRS).

- *RER* is a geometric mean of normalized edge response differences measured in two directions of image pixels (X and Y) at points distanced from the edge by -0.5 and 0.5 GSD.

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$$RER = \sqrt{[ER_X(0.5) - ER_X(-0.5)][ER_Y(0.5) - ER_Y(-0.5)]}$$
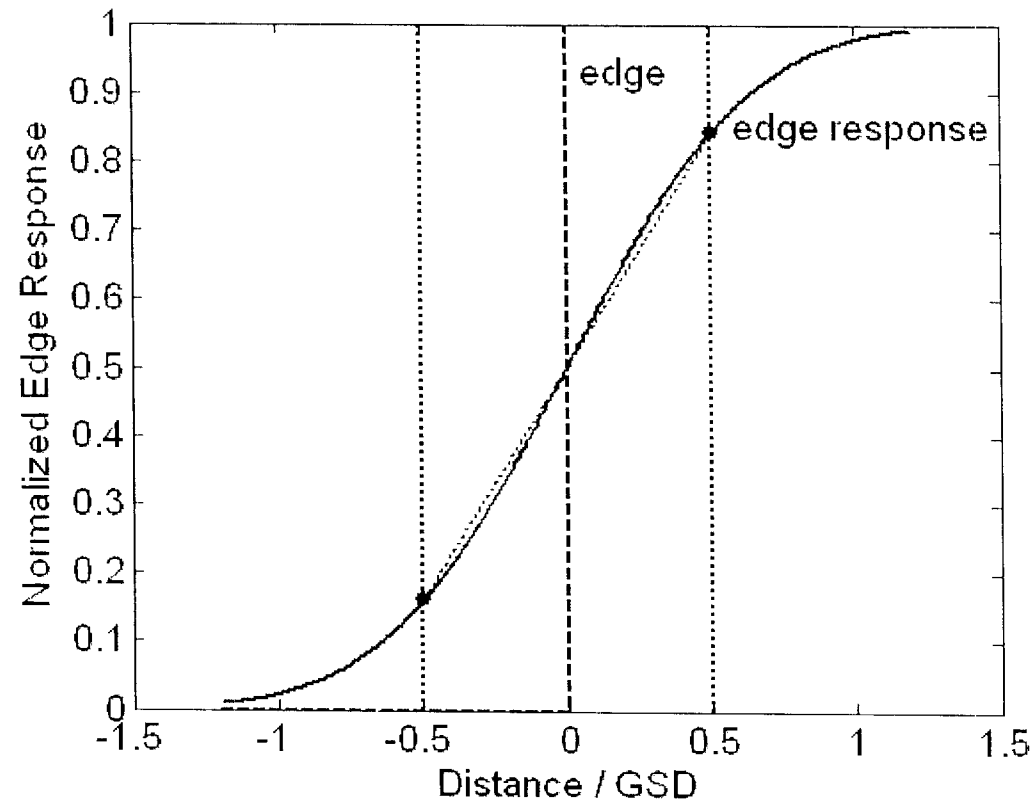
RER estimates effective slope of the imaging system's edge response because distance between the points for which the differences are calculated is equal to the GSD.

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# Spatial Assessment Approach

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- Edge responses are measured using a tilted-edge technique in which the response functions were approximated with a linear combination of an odd number of sigmoidal functions (chosen between 3 and 15 for the best fit).

- In the tilted-edge method, the edge target is intentionally oriented such that on an image, the edge is aligned slightly off-perpendicular to a pixel grid direction.

- Use of the tilted edge overcomes the main difficulty in applying the edge response method to digital images inherently based on limited, discrete spatial sampling.

- A small edge tilt causes pixels from adjacent lines to have their distance from the edge shifted by a fraction of the sampling distance.

- When shifted pixels from different lines are superimposed during the edge response analysis, the effective sampling distance of the derived edge response is smaller then that of the original image.
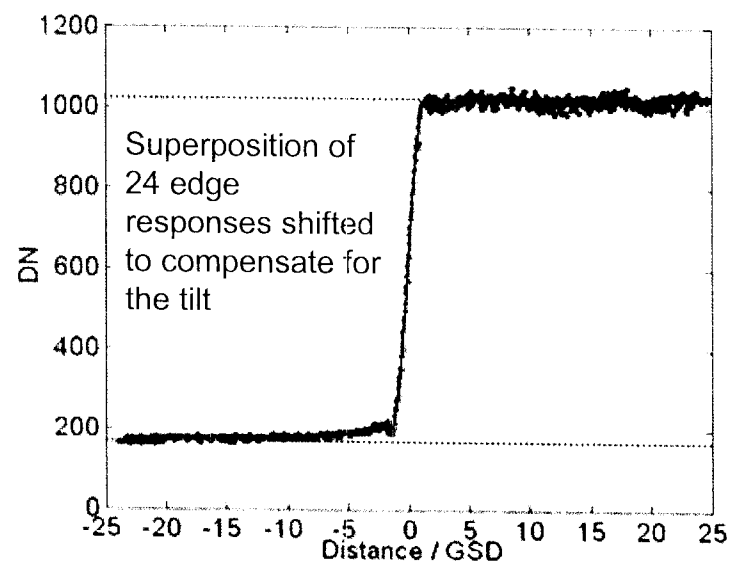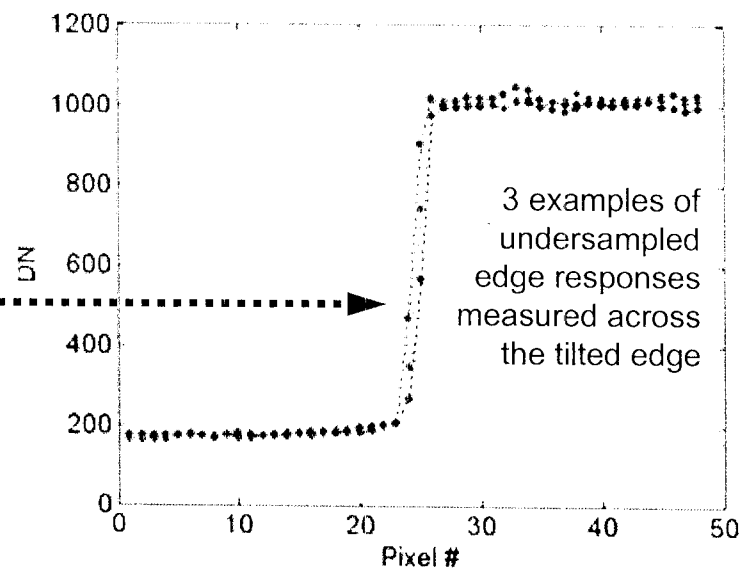
Edge Response

$$x = \delta \cos\theta$$

θ

δ
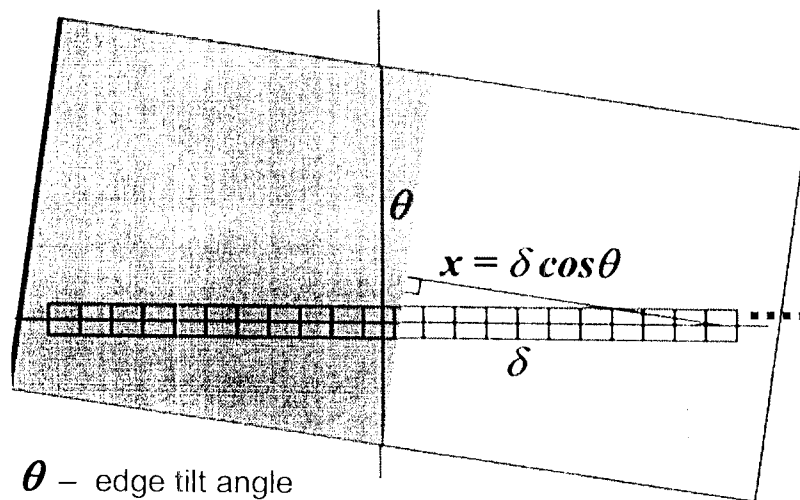
$\boldsymbol{\theta}$ – edge tilt angle

$\boldsymbol{\delta}$ – pixel index

x – pixel's distance from edge (in GSD)

Problem: Digital cameras undersample edge target

Solution: *Image tilted edge to improve sampling*

3 examples of undersampled edge responses measured across the tilted edge

DN

Pixel #

Superposition of 24 edge responses shifted to compensate for the tilt

DN

Distance / GSD

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Results to Date

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Emerge Sensor and Data

- Digital Sensor System (DSS)
  - System Manufacturer: Emerge
  - Lens Manufacturer: Zeiss
  - Array Size: 4092 x 4079 pixels
  - GSD: 0.10–1 m (platform and altitude dependent)
  - Spectral bands:
    - Color mode: 0.4–0.5 μm (Blue), 0.5–0.6 μm (Green), 0.6–0.68 μm (Red)
    - Color Infrared mode: 0.51–0.6 μm (Green), 0.6–0.7 μm (Red), 0.8–0.9 μm (NIR)
  - Direct Georeferencing System: Applanix POS AV
  - Platform: Cessna 172
- Delivered dataset
  - RGB orthorectified imagery acquired January 2003
    - 0.3-meter nominal GSD (~11.8 in)
    - GeoTIFF format (28 scenes to create mosaic)
    - No control used
    - NED DEM

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Emerge DSS
Sample Product Tile

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Very small portion
of one Emerge
data tile showing
an SSC geodetic
target
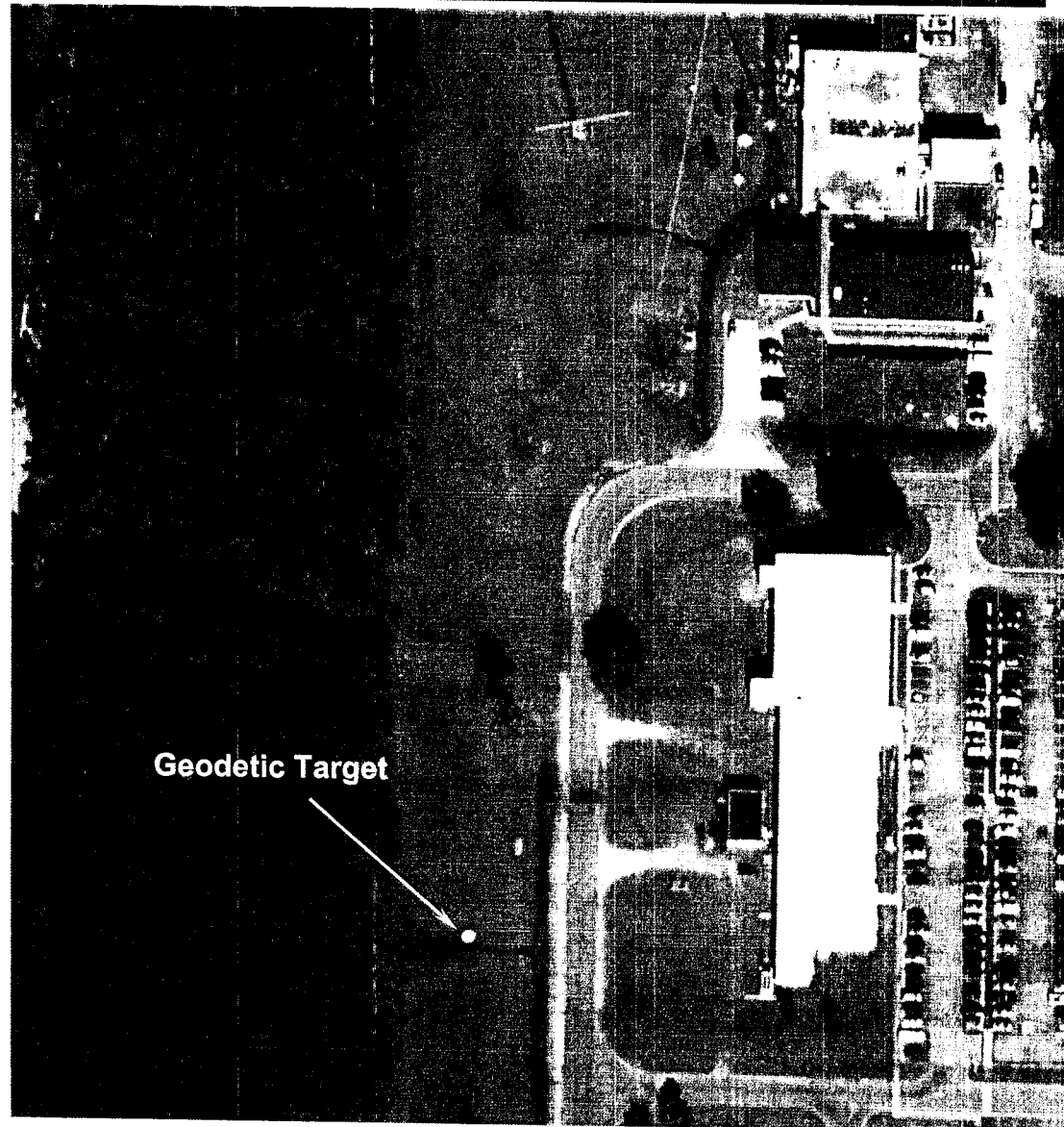
~I ft. GSD
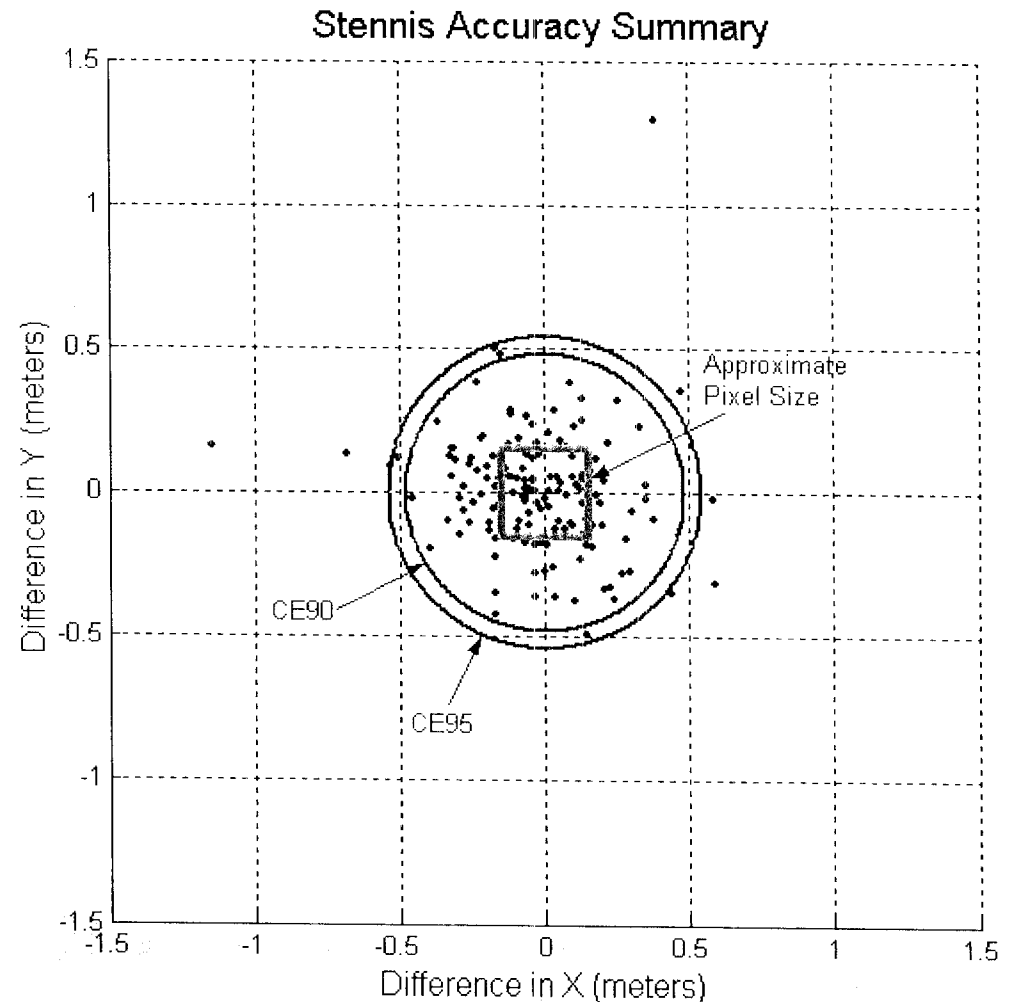

Geodetic Target

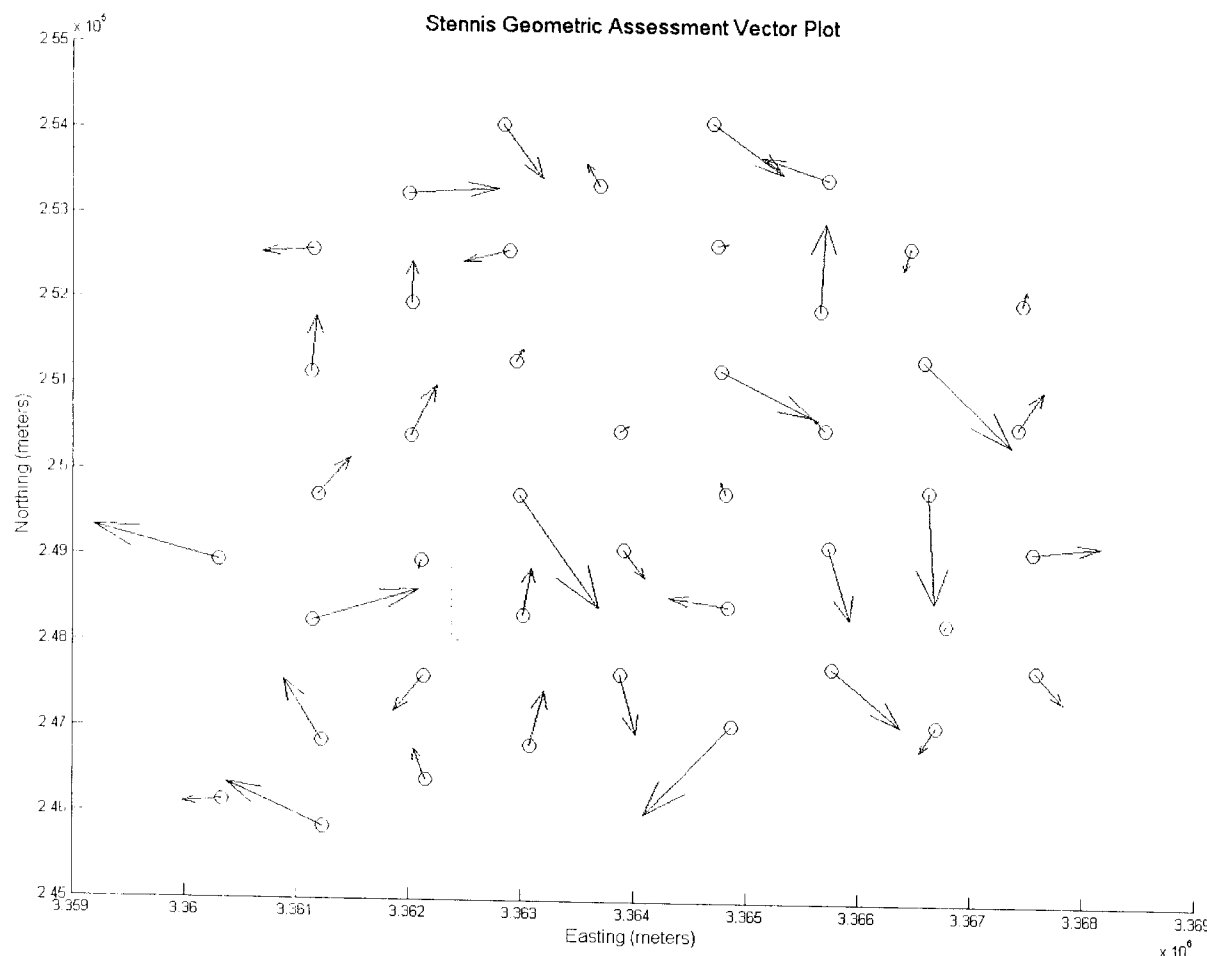**DRAFT**

Evaluated against SSC test control
- 150 targets located

Statistics Generated
- Total RMSE: 0.31 m (~12.2 in)
- CE90: 0.48 m (~18.9 in)
- CE95: 0.54 m (~19.68 in)

- No systematic bias detected

Stennis Accuracy Summary

Stennis Geometric Assessment Vector Plot

**Geodetic target residuals (manholes not included).
Vectors have been enlarged for visibility purposes. Vector magnitudes are
not absolute.**

- DAIS Sensor System
  - System Manufacturer: Dalsa
  - Lens Manufacturer: Nikon
  - Array Size: 1024 x 1024 pixels
  - GSD: 0.5–2 m (platform and altitude dependent)
  - Spectral bands: 0.45–0.53 µm (Blue), 0.52–0.61 µm (Green), 0.64–0.72 µm (Red), 0.77–0.88 µm (NIR)
  - Direct Georeferencing System: Applanix POS AV
  - Platform: Cessna 421C
- Delivered dataset: RGB orthorectified imagery acquired November 2003
  - 1-meter GSD 12-bit and 8-bit multispectral (4 separate bands)
  - 1-meter GSD 8-bit true color and false color composites
  - 0.5-meter GSD 8-bit and 16-bit multispectral (4 separate bands)
  - 0.5-meter GSD 8-bit true color and false color composites
  - GeoTIFF and ERDAS IMAGINE formats
  - NED DEM

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Very small portion
of one DAIS data
tile showing an
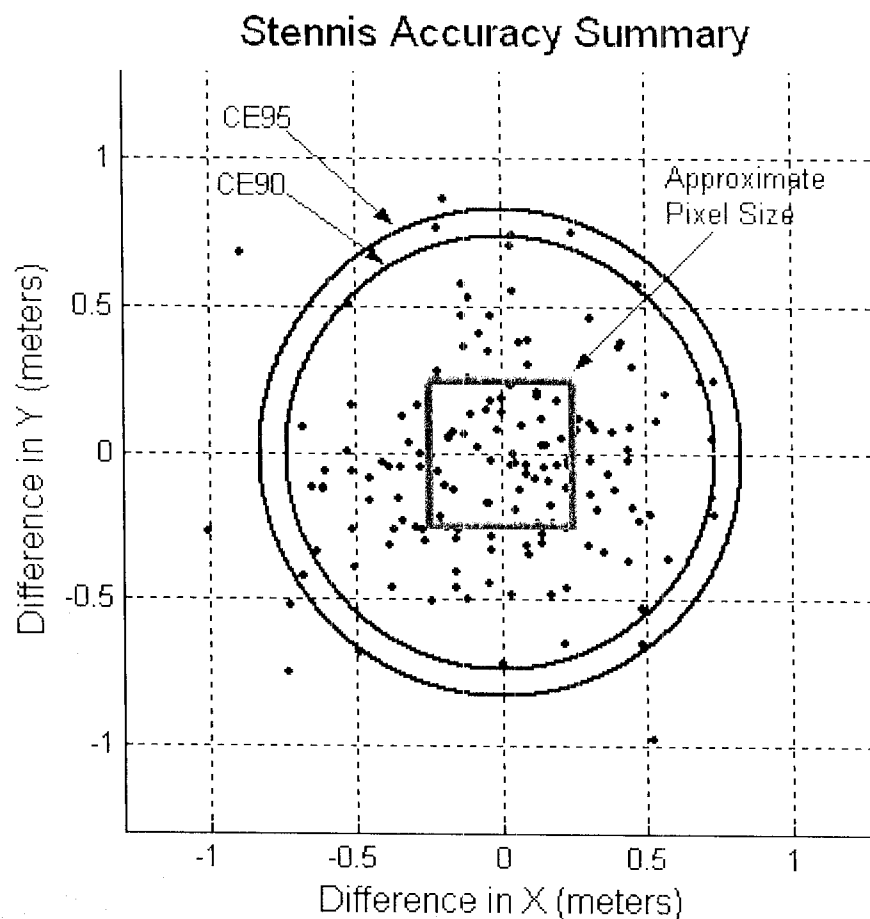SSC geodetic
target

~20 in. GSD

Geodetic Target

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RGB 0.5 m GSD, 8-bit dataset was used for this assessment

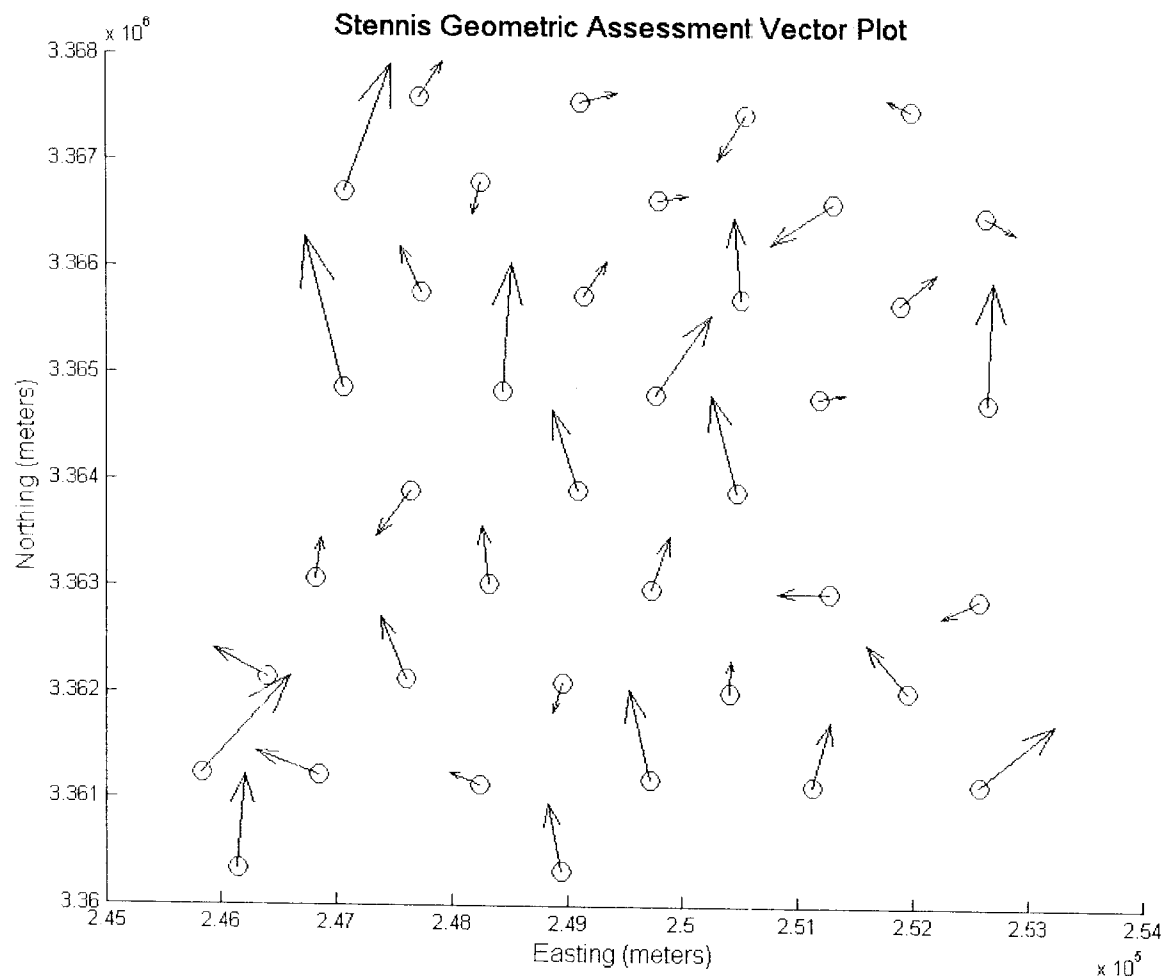Evaluated against SSC test control
• 150 ground targets located

Statistics Generated
• Total RMSE: 0.48 m (~18.9 in)
• CE90: 0.73 m (~28.7 in)
• CE95: 0.83 m (~32.7 in)

• No systematic bias detected

Stennis Accuracy Summary

DRAFT

Stennis Geometric Assessment Vector Plot

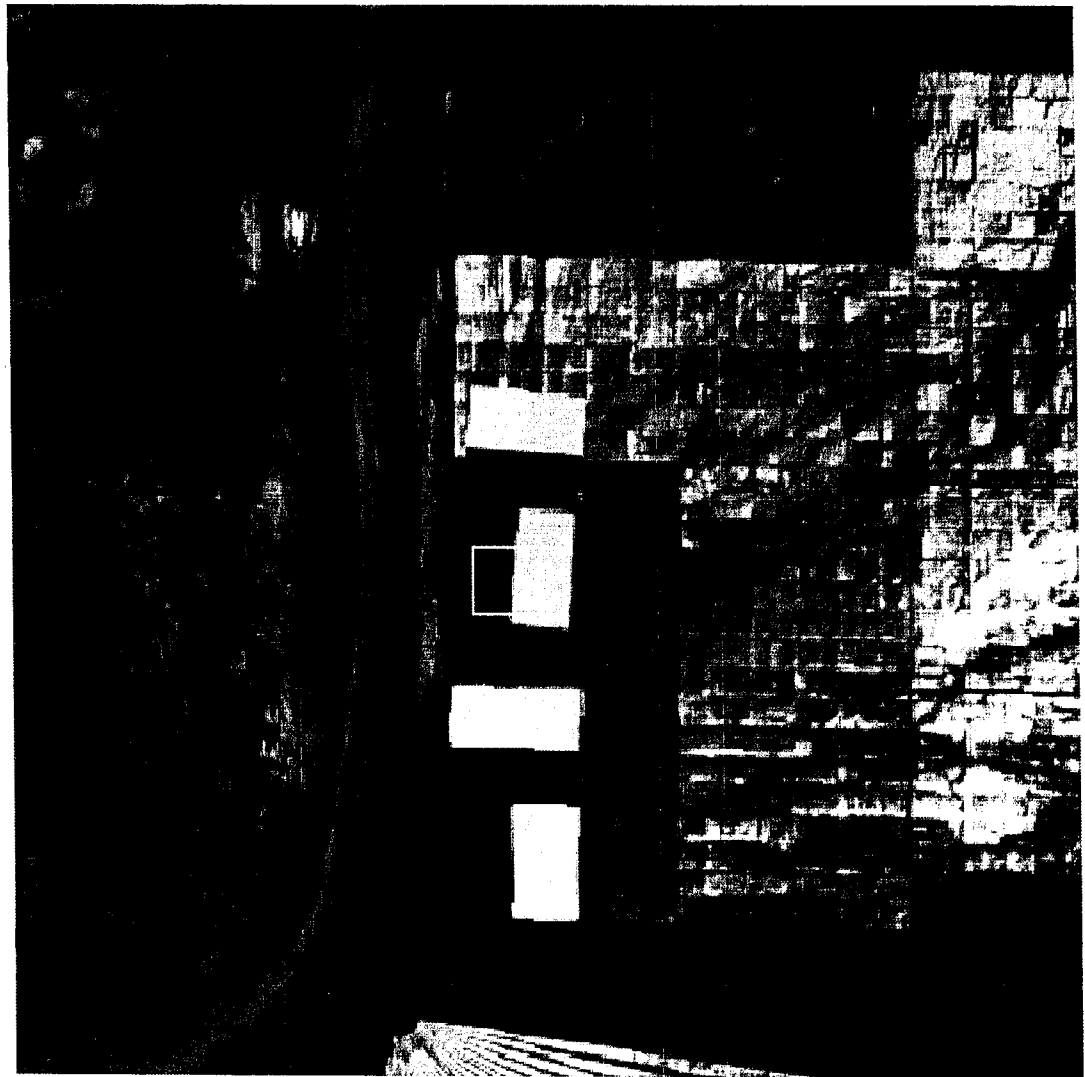**Geodetic target residuals (manholes not included). Vectors have been enlarged for visibility purposes. Vector magnitudes are not absolute.**

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16-bit, 0.5-meter GSD
multispectral imagery used
in analysis

Blue band is shown

Image area selected for
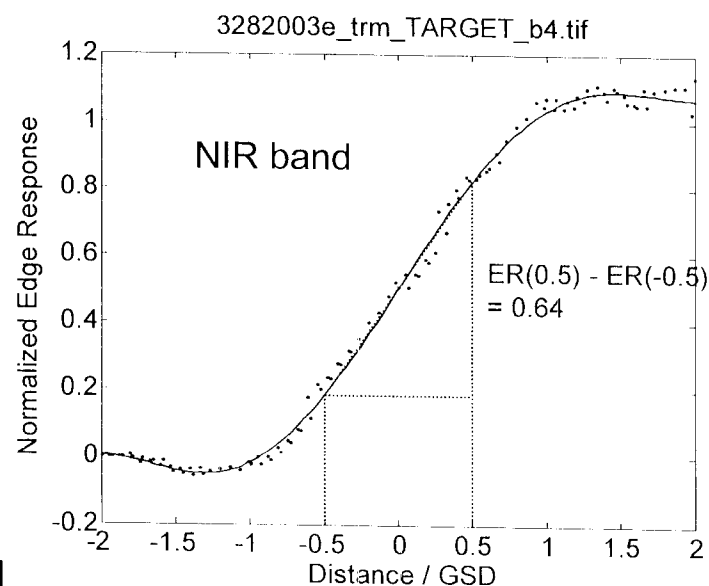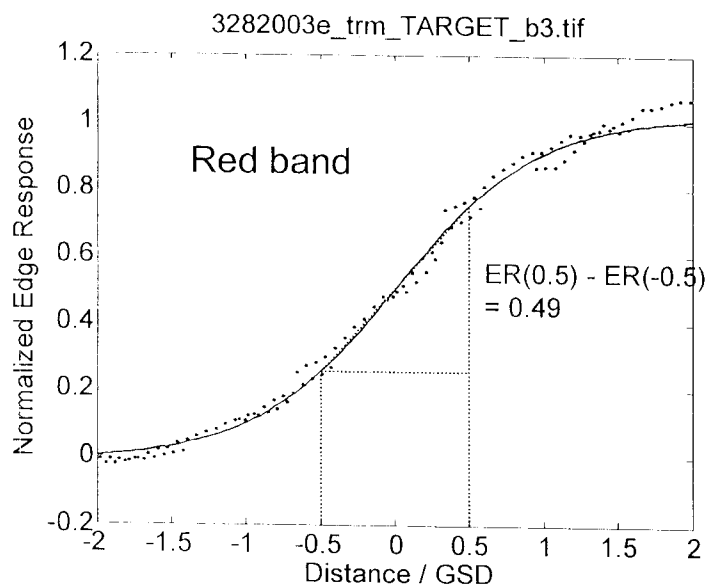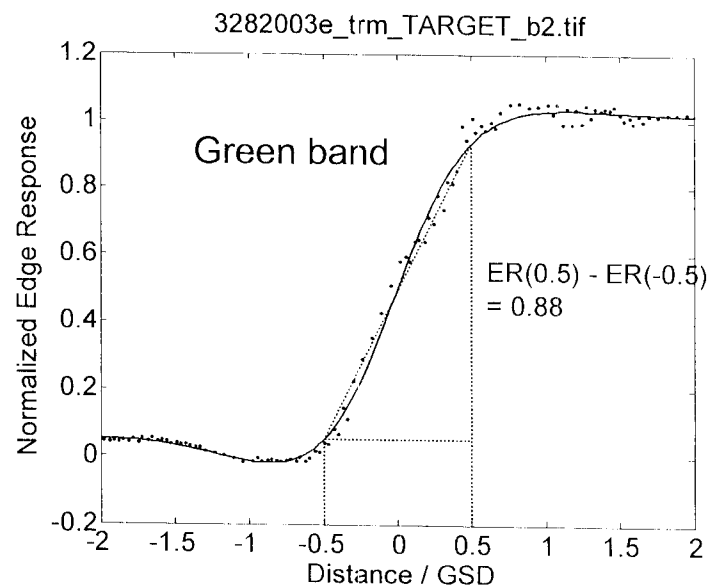spatial response
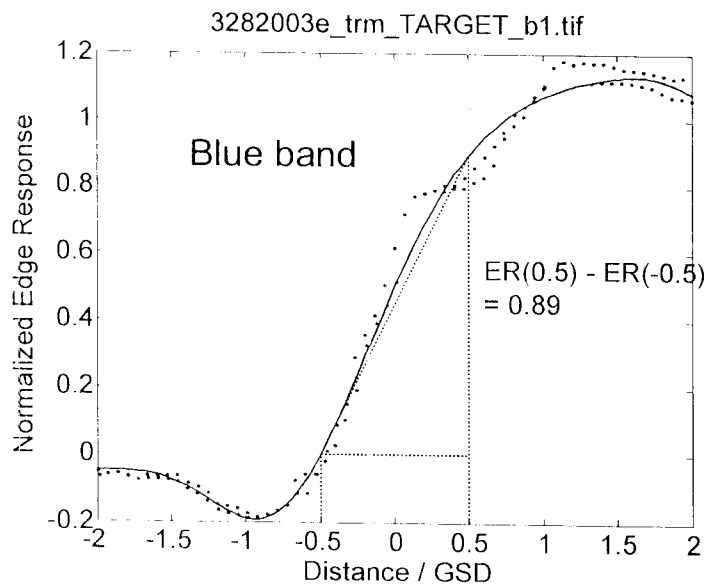measurement in Easting
direction

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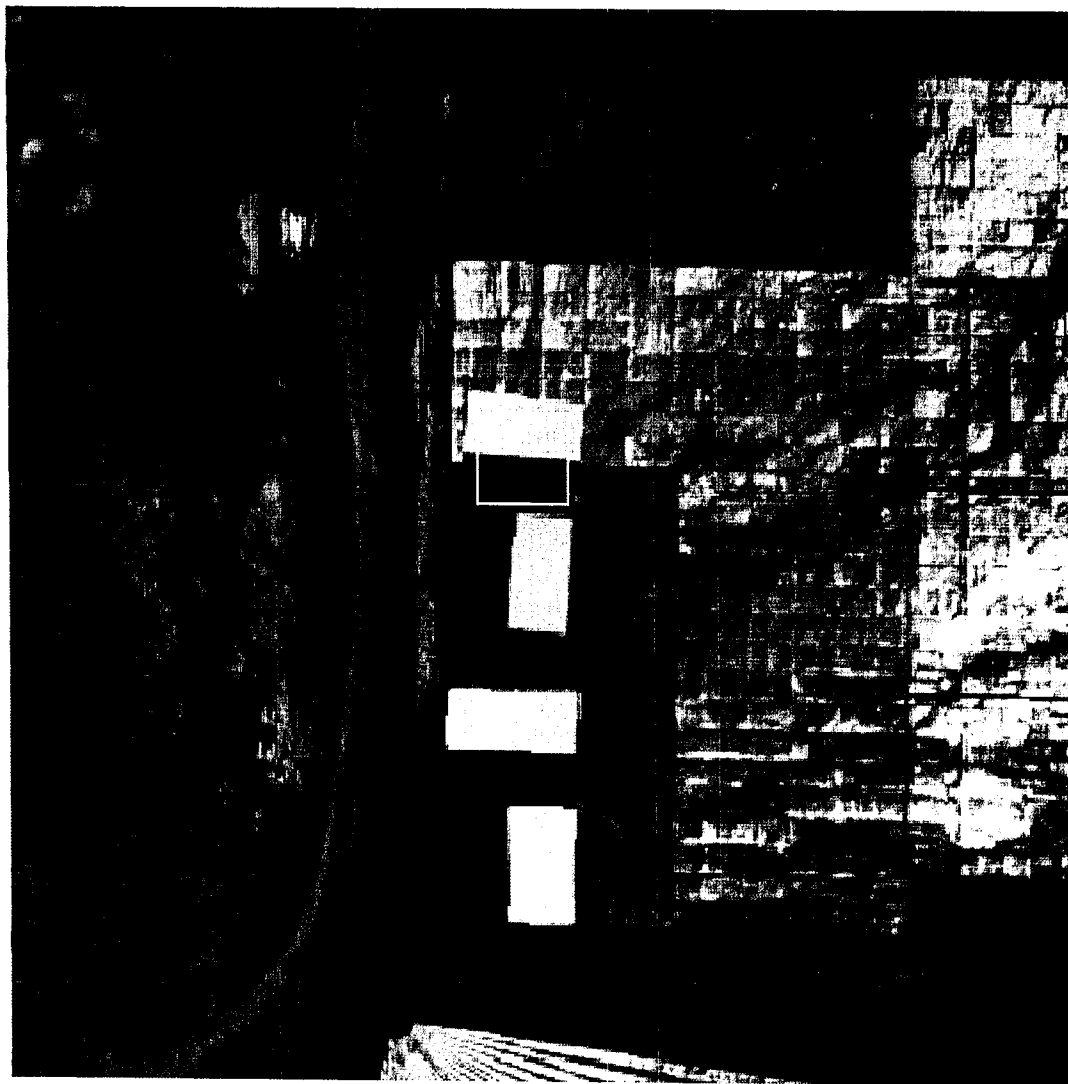# Space Imaging DAIS
Spatial Assessment Results

Easting Direction

3282003e_trm_TARGET_b1.tif

Blue band

ER(0.5) - ER(-0.5) = 0.89

3282003e_trm_TARGET_b2.tif

Green band

ER(0.5) - ER(-0.5) = 0.88

3282003e_trm_TARGET_b3.tif

Red band

ER(0.5) - ER(-0.5) = 0.49

3282003e_trm_TARGET_b4.tif

NIR band

ER(0.5) - ER(-0.5) = 0.64

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16-bit, 0.5-meter GSD
multispectral imagery used
in analysis

Blue band is shown

Image area selected for
spatial response
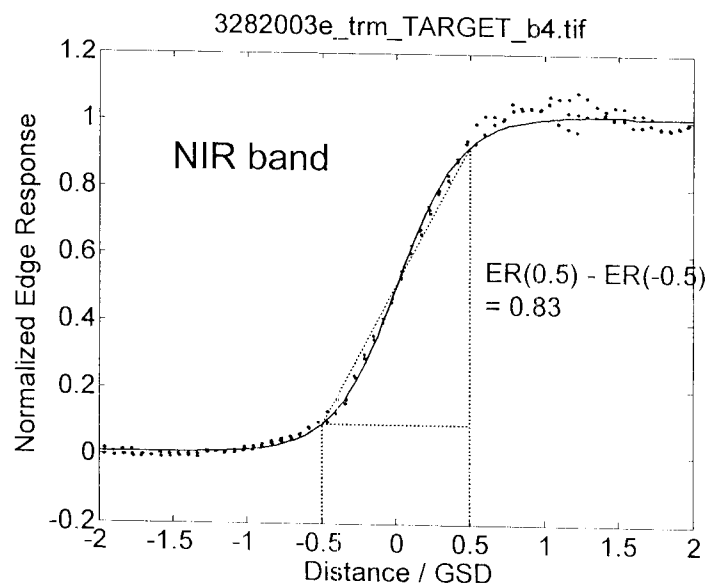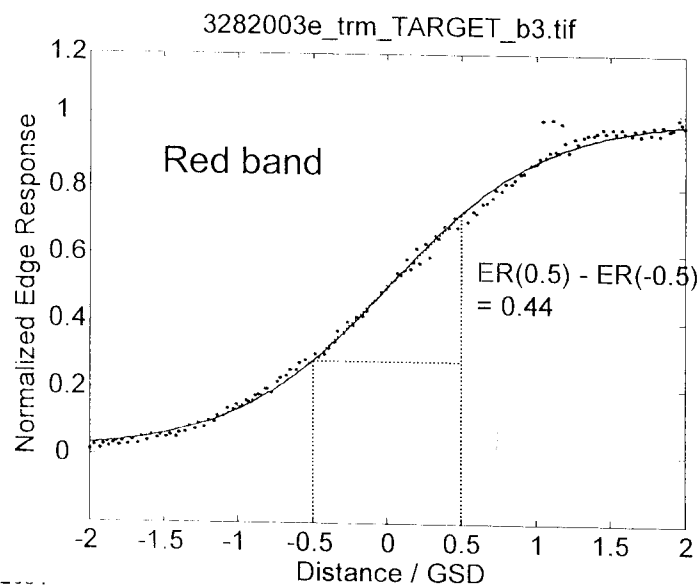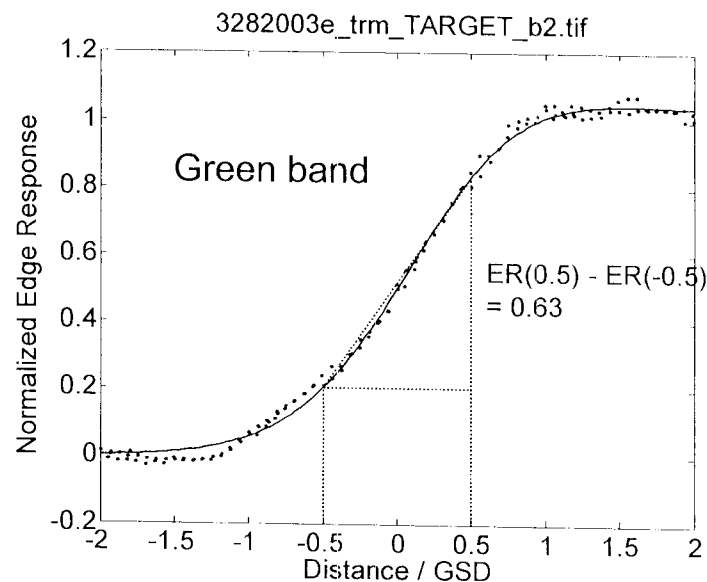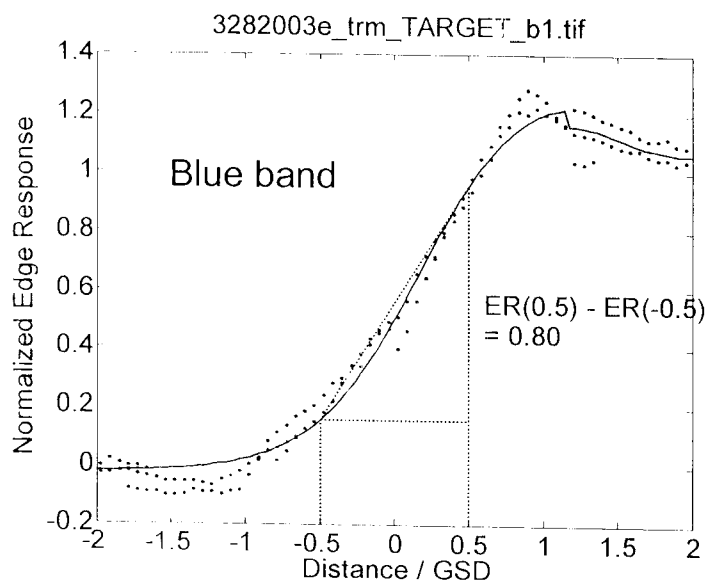measurement in Northing
direction

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Northing Direction

3282003e_trm_TARGET_b1.tif

Blue band

ER(0.5) - ER(-0.5) = 0.80

3282003e_trm_TARGET_b2.tif

Green band

ER(0.5) - ER(-0.5) = 0.63

3282003e_trm_TARGET_b3.tif

Red band

ER(0.5) - ER(-0.5) = 0.44

3282003e_trm_TARGET_b4.tif

NIR band

ER(0.5) - ER(-0.5) = 0.83

ASPRS, Denver, May

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Band	ER(0.5) - ER(-0.5)		RER
	Easting Direction	*Northing Direction*	
blue	0.89	0.80	0.8
green	0.88	0.63	0.7
red	0.49	0.44	0.5
NIR	0.64	0.83	0.7

- The mean RER for all bands is approximately 0.7.
- RER for the red band differs from the other bands.
  - This may negatively affect comparisons of the red band image with the other bands such as with the NIR band in calculations of the Normalized Difference Vegetation Index (NDVI).
- Uncertainty of spatial resolution characterization results were increased by using nearest-neighbor resampling in processing of the provided DAIS image products.
- The uncertainty was also enlarged by small (~3%) non-uniformity of radiometric response ("banding") observed in the images (mainly for the blue band).

- ADS40 Sensor System
  - System manufacturer: Leica
  - Lens Manufacturer: ?????
  - Array Size: 12000 x 1 pixels
  - GSD: 0.15–0.6 m (typical, platform, and altitude dependent)
  - Spectral bands: 0.47–0.68 µm (Pan), 0.43–0.49 µm (Blue), 0.54–0.59 µm (Green), 0.61–0.66 µm (Red), 0.84–0.89 µm (NIR)
  - Direct Georeferencing System: ADS40 internal
  - Platform: Piper Navajo Chieftain

- Delivered dataset: Pan, NIR, and RGB orthorectified imagery
  - 0.25-meter GSD
  - GeoTIFF format
  - NED DEM

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Very small portion
of one ADS40 data
tile showing an SSC
geodetic target

~10 in. GSD

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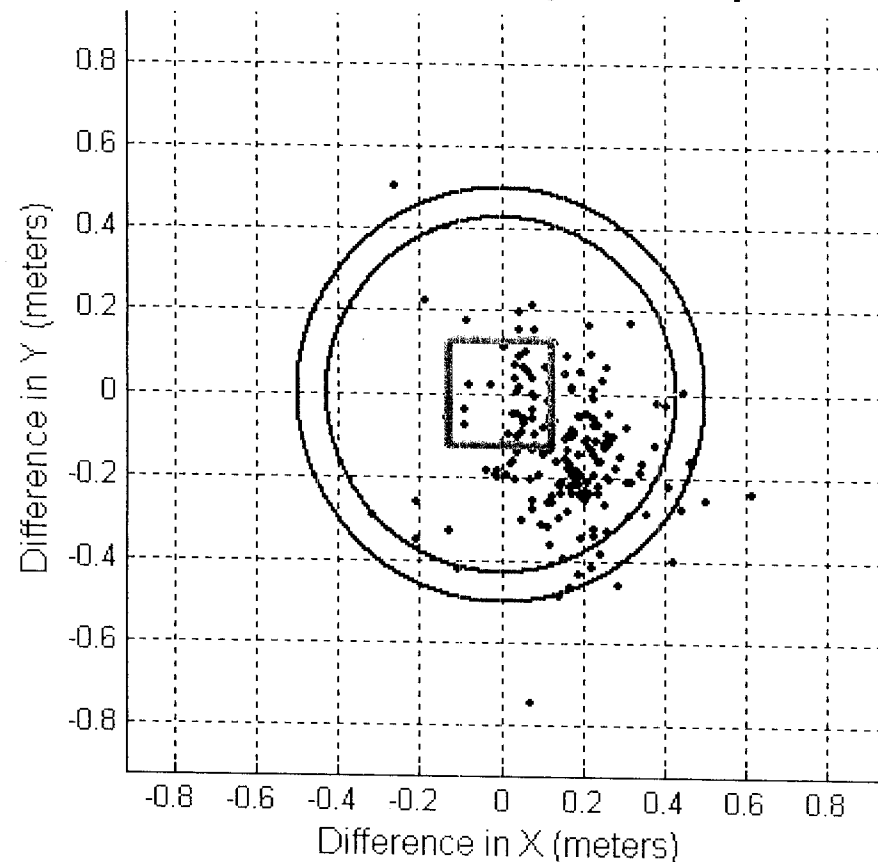*science for a changing world*

RGB 0.25 m GSD dataset
used in analysis

Evaluated against SSC test control
- 183 ground targets located

Statistics Generated
- Total RMSE: 0.29 m (~11 in)
- CE90: 0.44 m (~17 in)
- CE95: 0.50 m (~20 in)

- Systematic bias of 0.16 m
  detected
- Because $\sigma/_{Bias} \approx 1$ the FGDC CE_{90}
  definition still yields accurate
  results
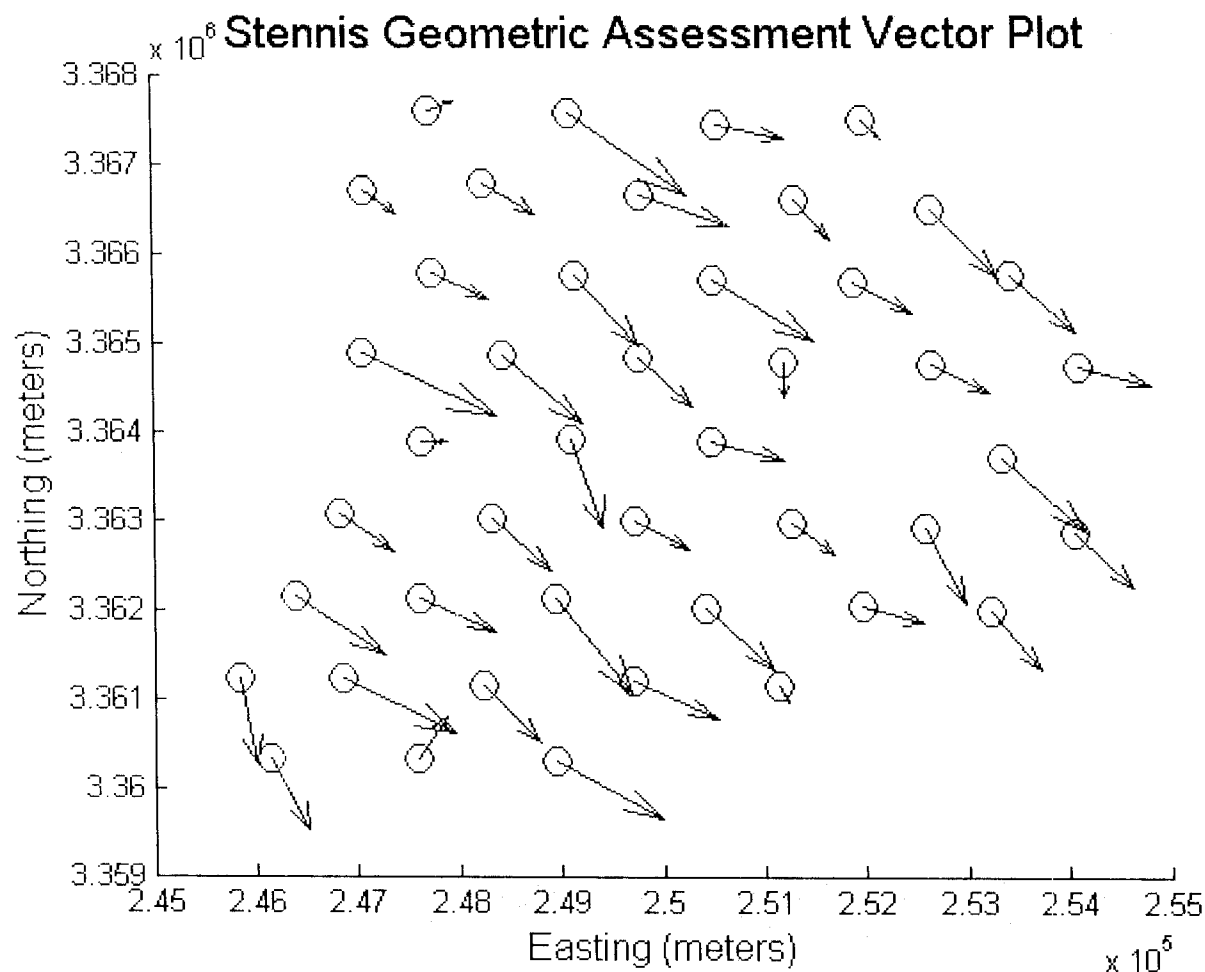
Stennis Accuracy Summary

Difference in Y (meters)

Difference in X (meters)

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Stennis Geometric Assessment Vector Plot

Geodetic target residuals (manholes not included).
Vectors have been enlarged for visibility purposes. Vector magnitudes are not absolute.
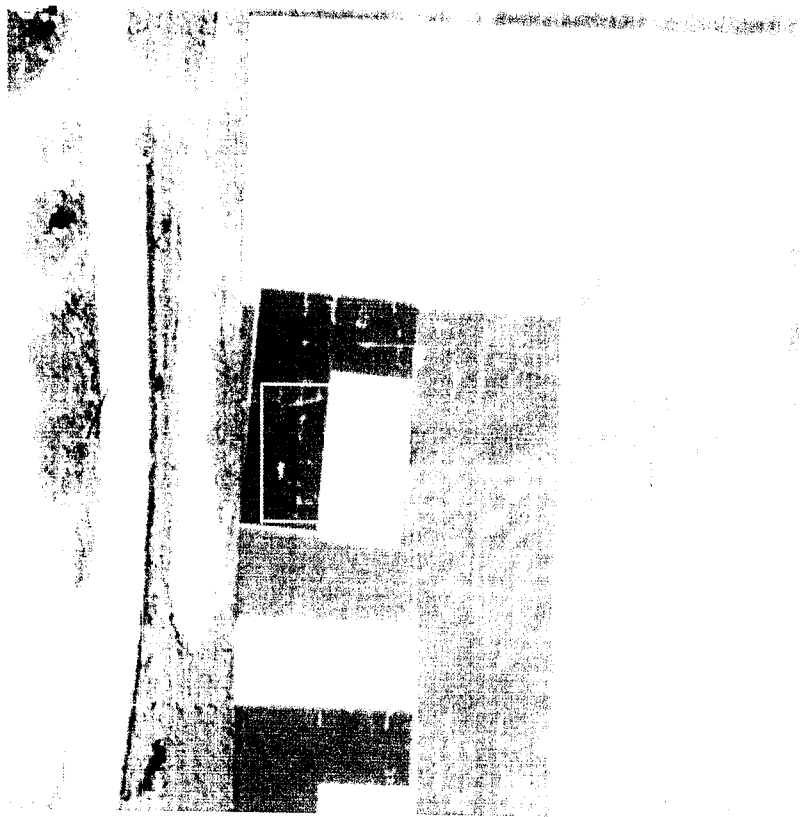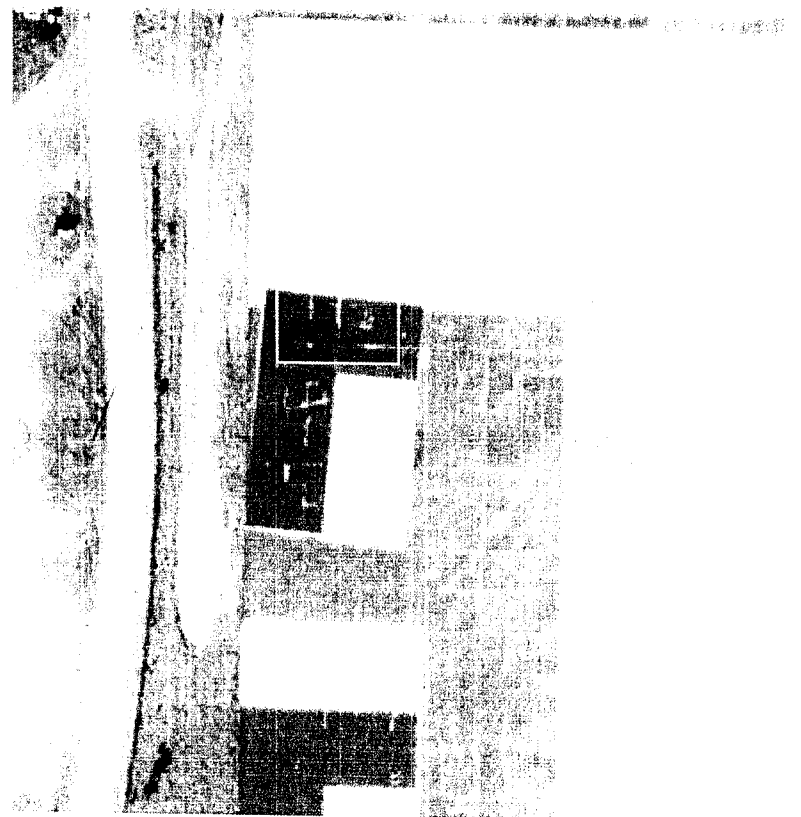
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EarthData ADS40
Spatial Assessment Results

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8-bit, 0.25-meter GSD panchromatic images used in analysis

*Image area selected for spatial response
measurement in Easting direction*

*Image area selected for spatial response
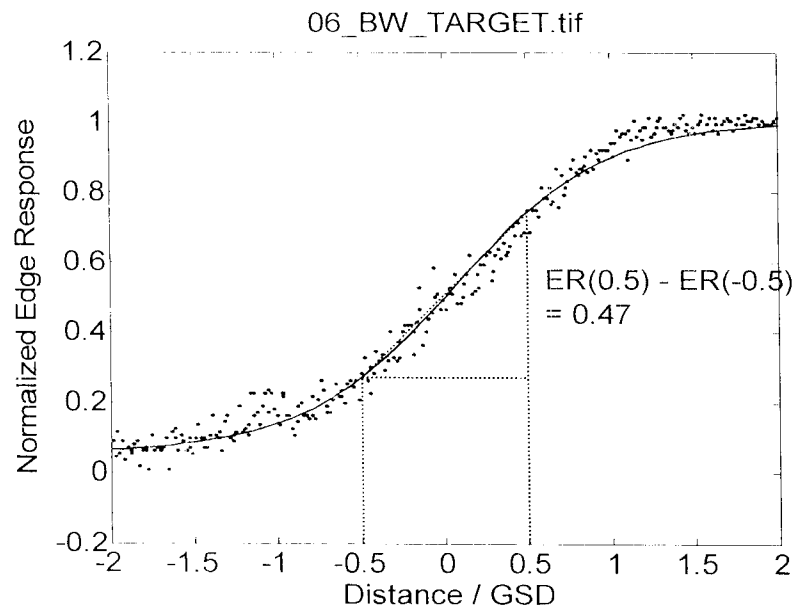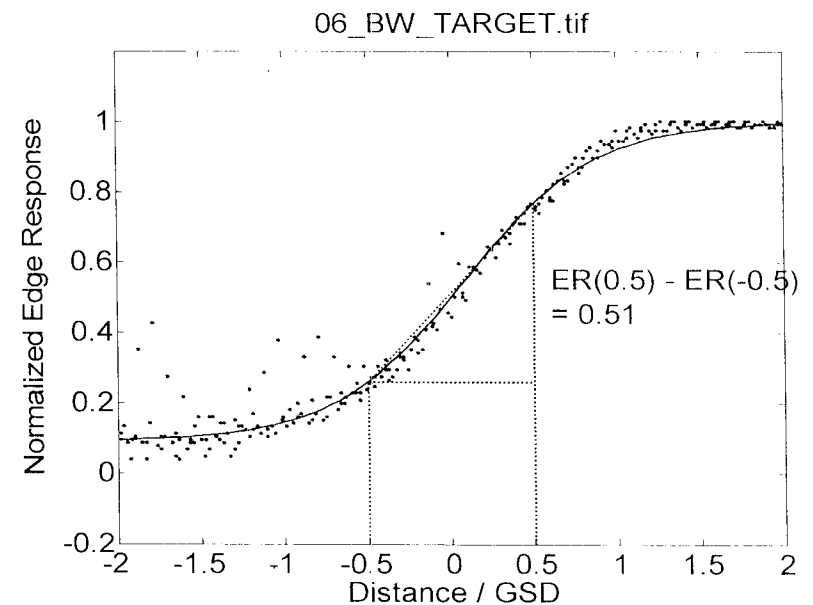measurement in Northing direction*

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Edge responses measured for the panchromatic image

06_BW_TARGET.tif

$ER(0.5) - ER(-0.5)$
$= 0.47$

06_BW_TARGET.tif

$ER(0.5) - ER(-0.5)$
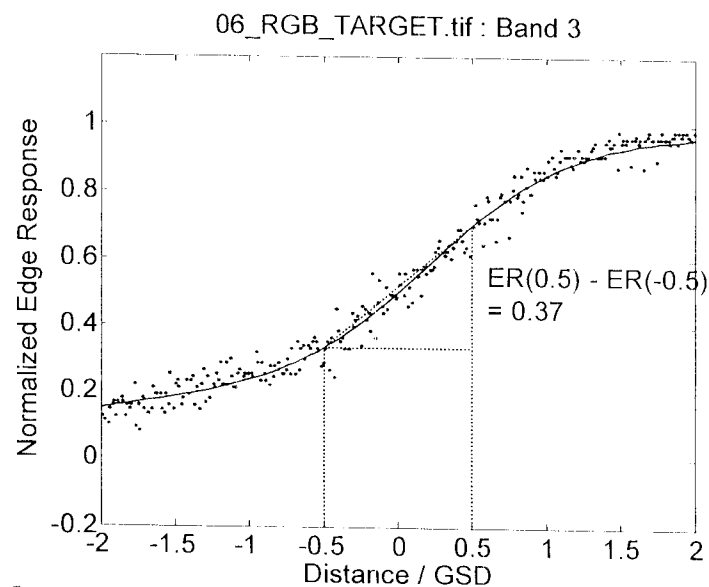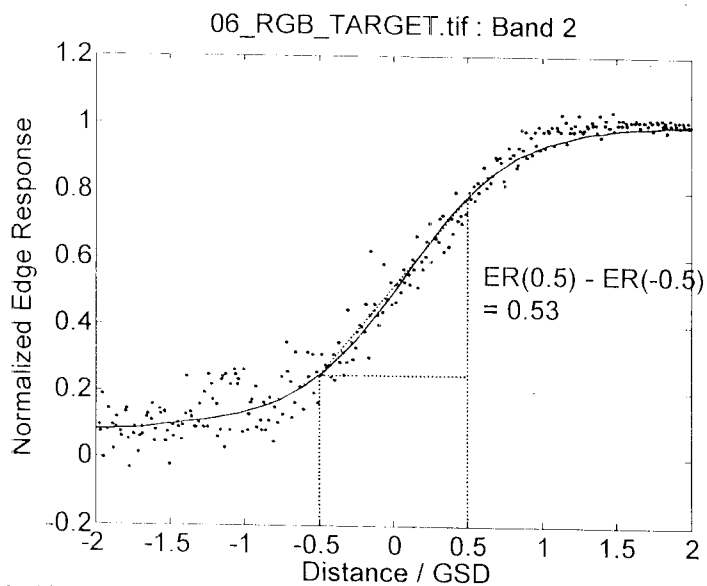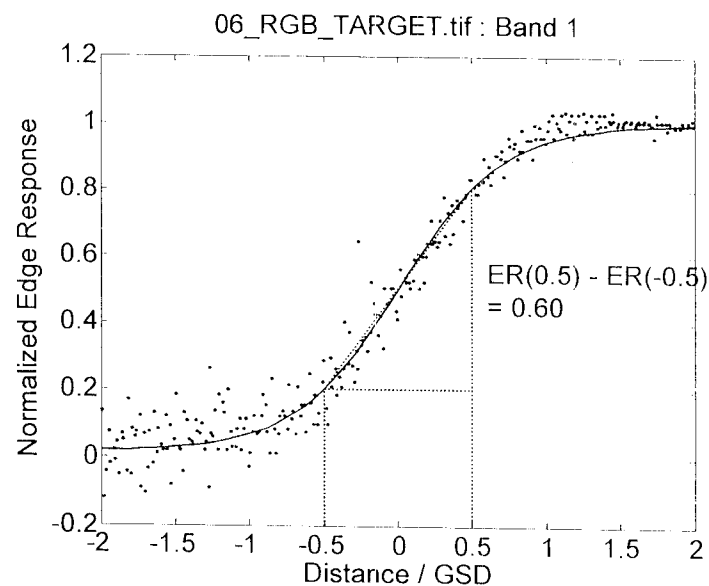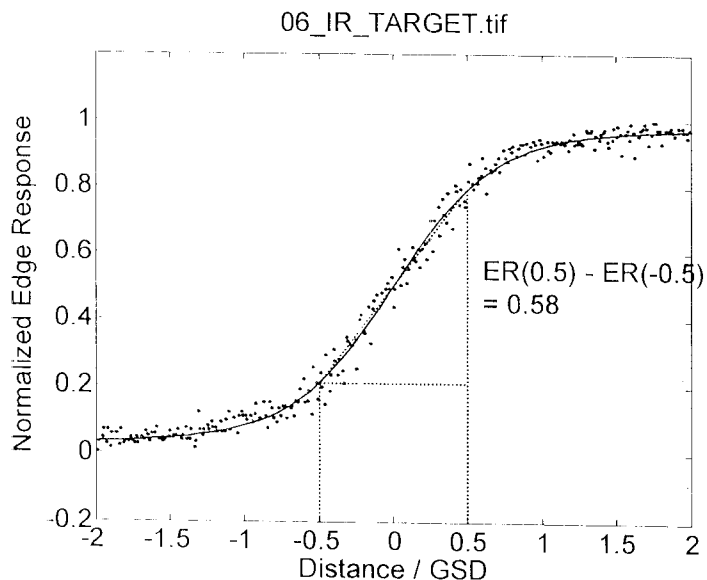$= 0.51$

Easting direction

Northing direction

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EarthData ADS40
Spatial Assessment Results

Easting Direction

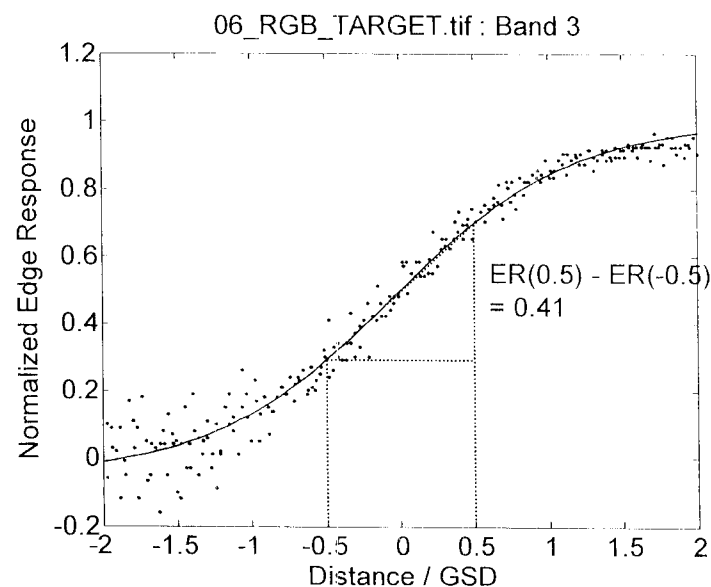## 06_IR_TARGET.tif

ER(0.5) - ER(-0.5) = 0.58

06_RGB_TARGET.tif : Band 1

ER(0.5) - ER(-0.5) = 0.60

06_RGB_TARGET.tif : Band 2

ER(0.5) - ER(-0.5) = 0.53

06_RGB_TARGET.tif : Band 3

ER(0.5) - ER(-0.5) = 0.37

ASPRS, Denver, Ma

Northing Direction

06_IR_TARGET.tif

ER(0.5) - ER(-0.5) = 0.65

06_RGB_TARGET.tif : Band 1

ER(0.5) - ER(-0.5) = 0.48

06_RGB_TARGET.tif : Band 2

ER(0.5) - ER(-0.5) = 0.57

06_RGB_TARGET.tif : Band 3

ER(0.5) - ER(-0.5) = 0.41

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EarthData ADS40
Spatial Assessment Results

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Band	ER(0.5) - ER(-0.5)		RER
	Easting Direction	*Northing Direction*	
Pan	0.47	0.51	0.5
NIR	0.58	0.65	0.6
Red	0.60	0.48	0.5
Green	0.53	0.57	0.6
Blue	0.37	0.41	0.4

- The mean RER for all bands is approximately 0.5.

- Uncertainty of spatial resolution characterization results was increased by the higher level of noise present in images of the dark panels of the edge targets, in comparison to images of the bright panels.

- This does not follow usual performance of detector-noise-limited imaging systems (equal noise) or photon-noise-limited systems (noise higher for the bright panels).

- It may be an indication of a non-linear (e.g., logarithmic-like) radiometric response of the EarthData's ADS40 system.

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IKONOS Sensor and Data

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- IKONOS Sensor System
  - System manufacturer: Eastman Kodak
  - Lens Manufacturer: Eastman Kodak
  - Array Size: 11300 x 1 pixels
  - GSD: 1 m (Pan), 4 m (Multispectral)
  - Spectral bands: 0.45–0.90 µm (Pan), 0.45–0.52 µm (Blue), 0.51–0.60 µm (Green), 0.63–0.70 µm (Red), 0.76–0.85 µm (NIR)
  - Direct Georeferencing System: ???
  - Platform: IKONOS-2 Satellite

- Delivered dataset: Pan and RGB high accuracy digital imagery
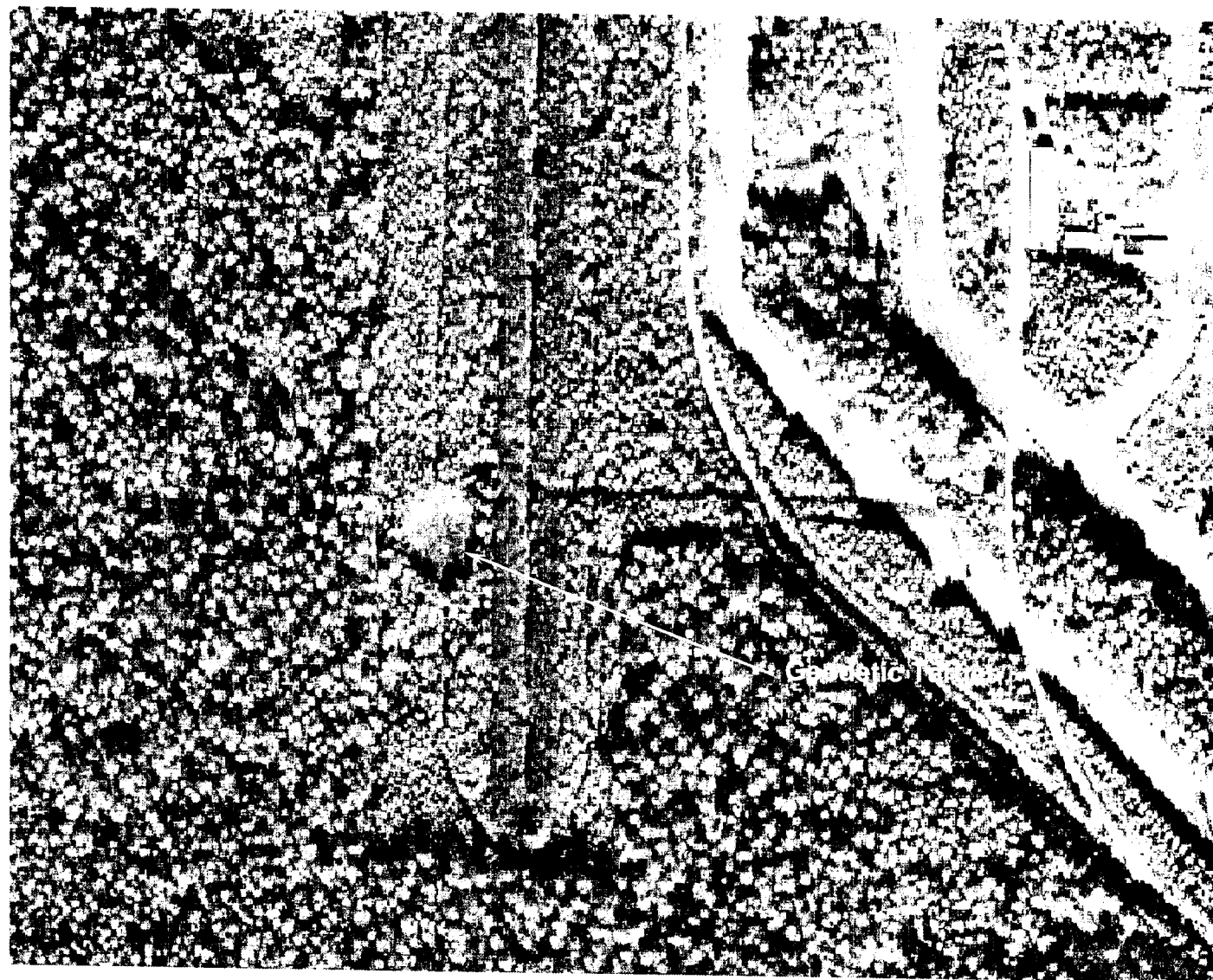 - 1.0-meter GSD
  - GeoTIFF format
  - NED DEM

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Very small portion of
the IKONOS
panchromatic image
showing an SSC
geodetic target

~1 m GSD

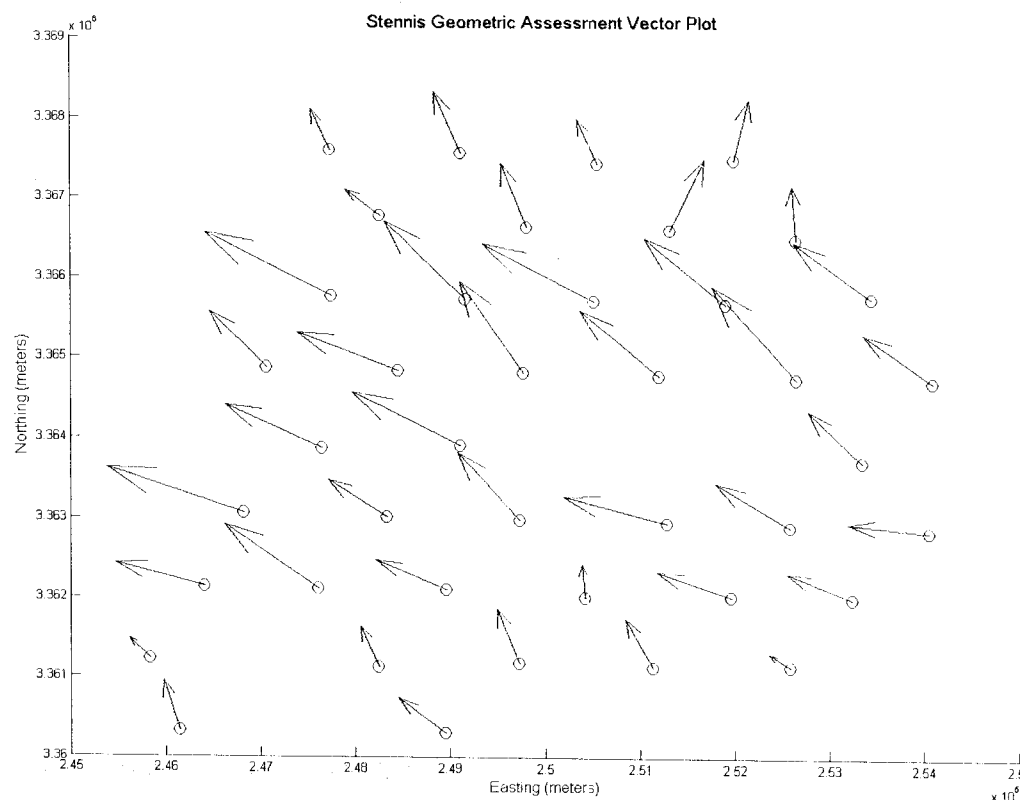**DRAFT**

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Pan 1.0 m GSD dataset used in analysis

Evaluated against SSC test control
- 41 ground targets located

Statistics Generated
- Total RMSE: 1.65 m (~5 ft)
- CE90: 2.50 m (~8 ft)
- CE95: 2.85 m (~9 ft)

- Systematic bias of 1.44 m detected
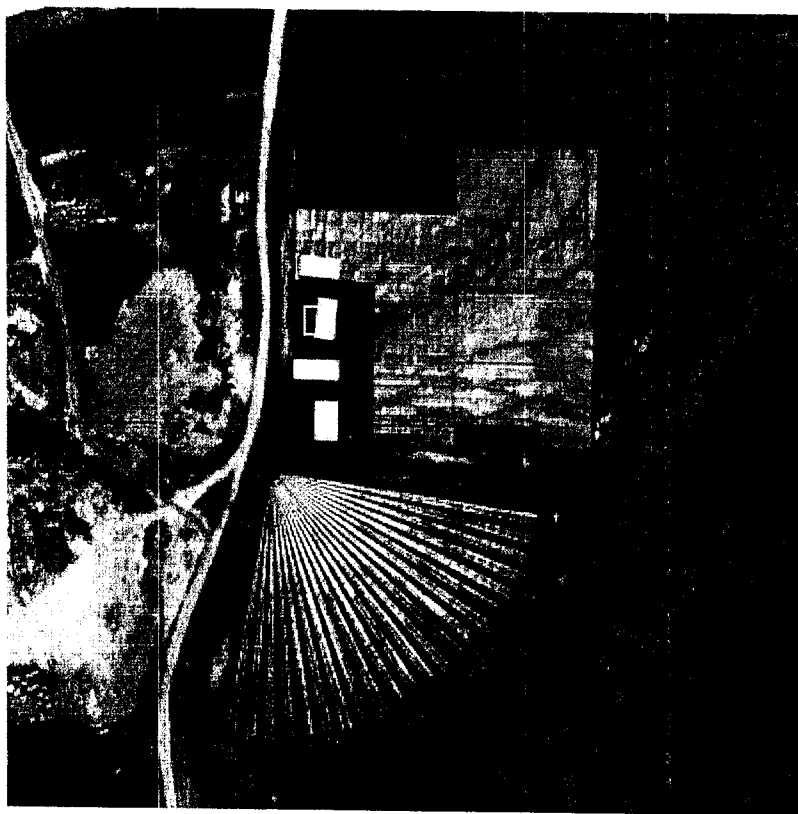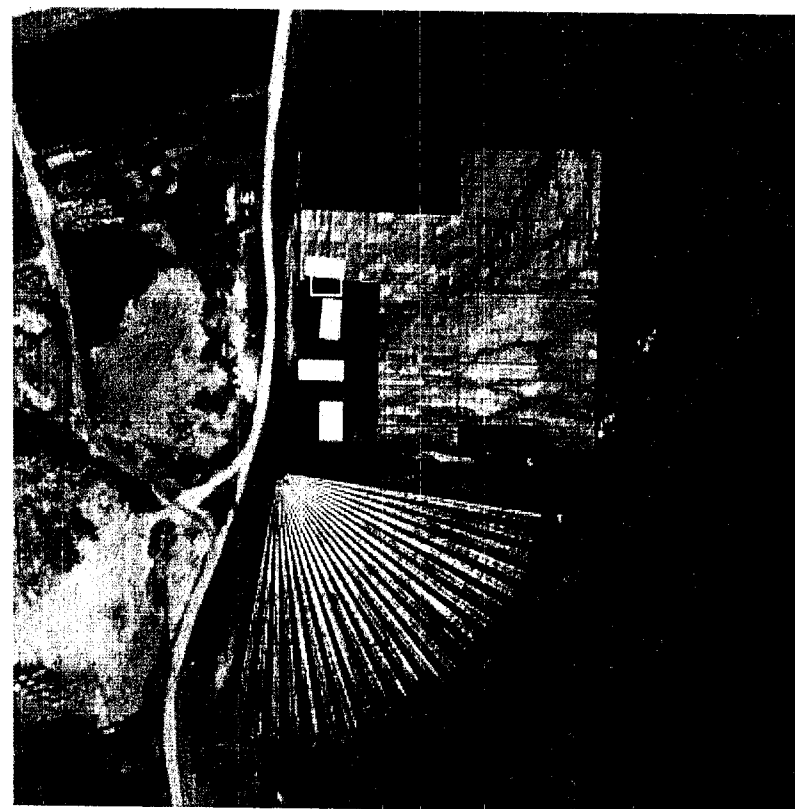- Because $\sigma/_{Bias} \approx 1$ the FGDC CE_{90} definition still yields accurate results

Stennis Geometric Assessment Vector Plot

11-bit, 1.0-meter GSD panchromatic images used in analysis

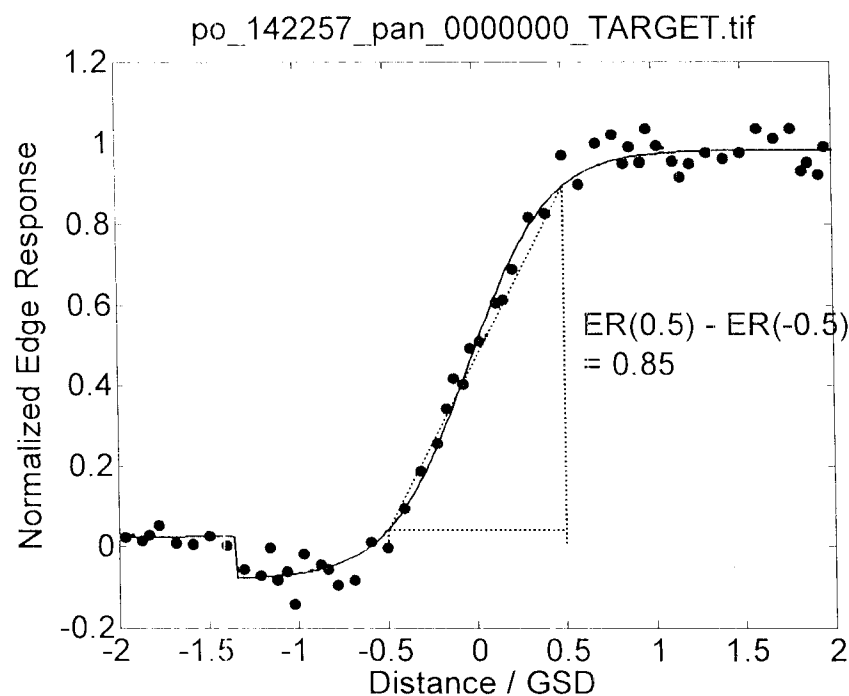*Image area selected for spatial response measurement in Easting direction*

Image area selected for spatial response measurement in Northing direction

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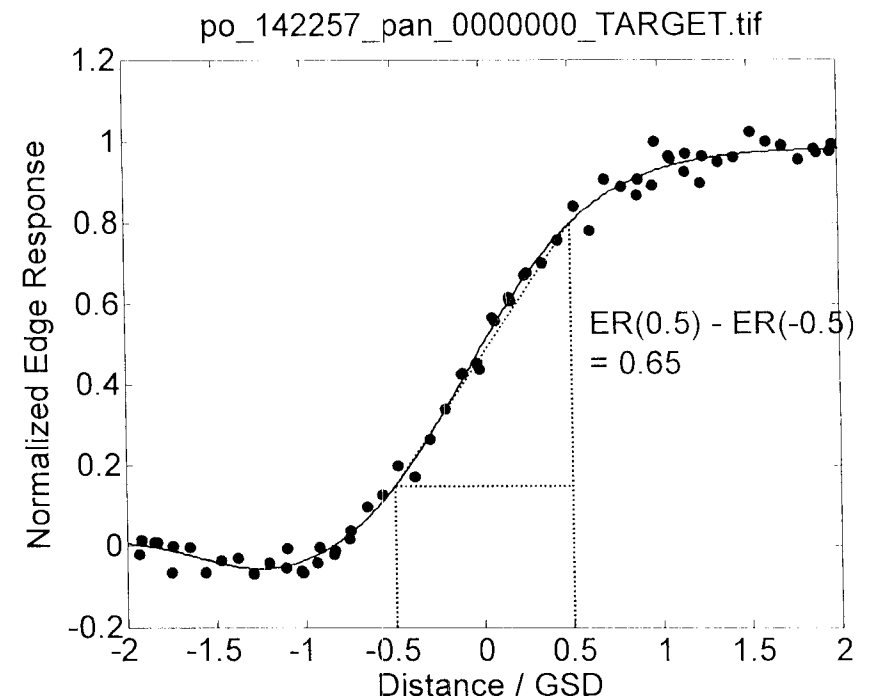# Edge responses measured for the panchromatic image

po_142257_pan_0000000_TARGET.tif

ER(0.5) - ER(-0.5) = 0.85

Easting direction

po_142257_pan_0000000_TARGET.tif

ER(0.5) - ER(-0.5) = 0.65

Northing direction

ASPRS, Denver, May 2004

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Space Imaging IKONOS
Spatial Assessment Results

Band	ER(0.5) - ER(-0.5)		RER
	Easting Direction	*Northing Direction*	
pan	0.85	0.65	0.7

Only the panchromatic image product was evaluated because of limitations imposed by size of the edge targets

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Next Steps

- Perform geopositional and spatial assessments for the following systems, upon data delivery:
  - NW Geomatics
  - Aerometric

- Perform absolute radiometric assessments
  - Coordinate acquisition window that can accommodate multiple systems in order to minimize costs of analysis

- Perform geopositional assessment of 3001, Inc., LIDAR data

Questions???

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Backup

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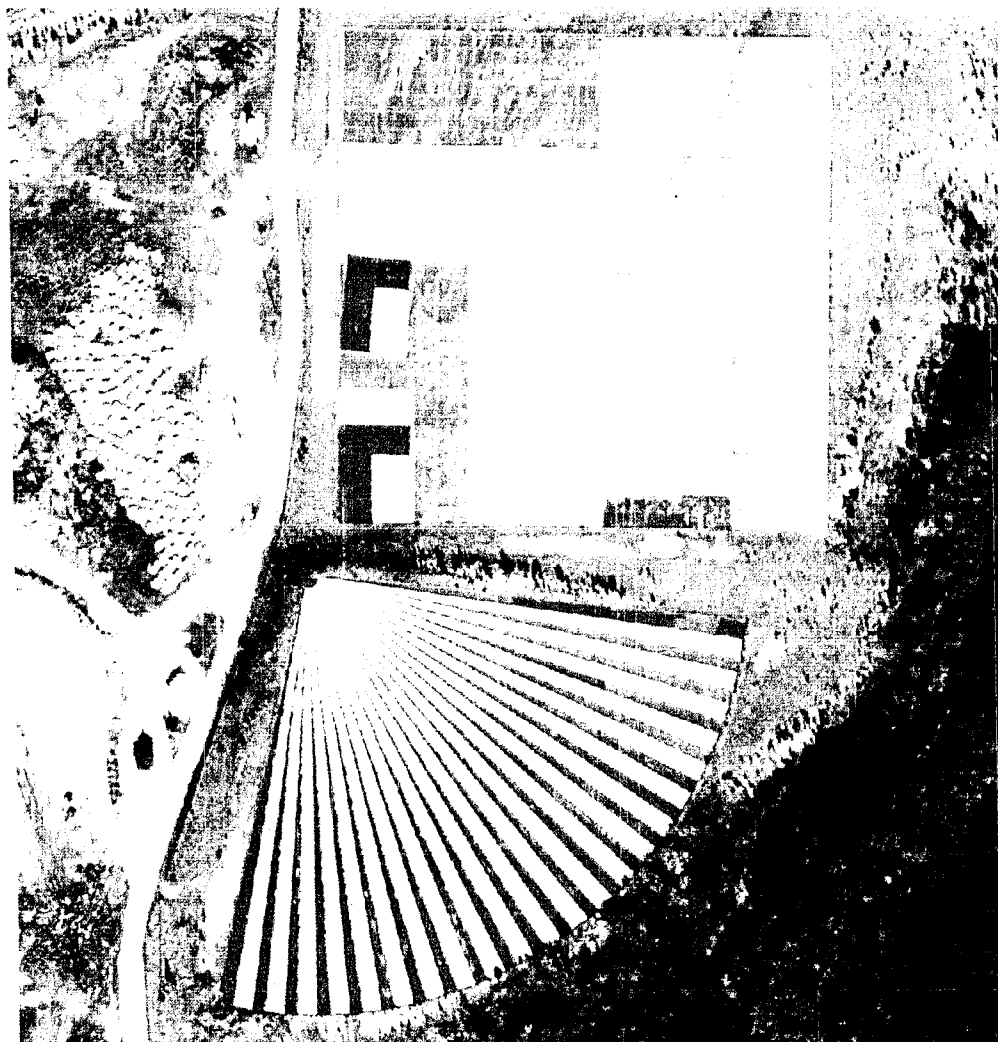Menlo Park, CA
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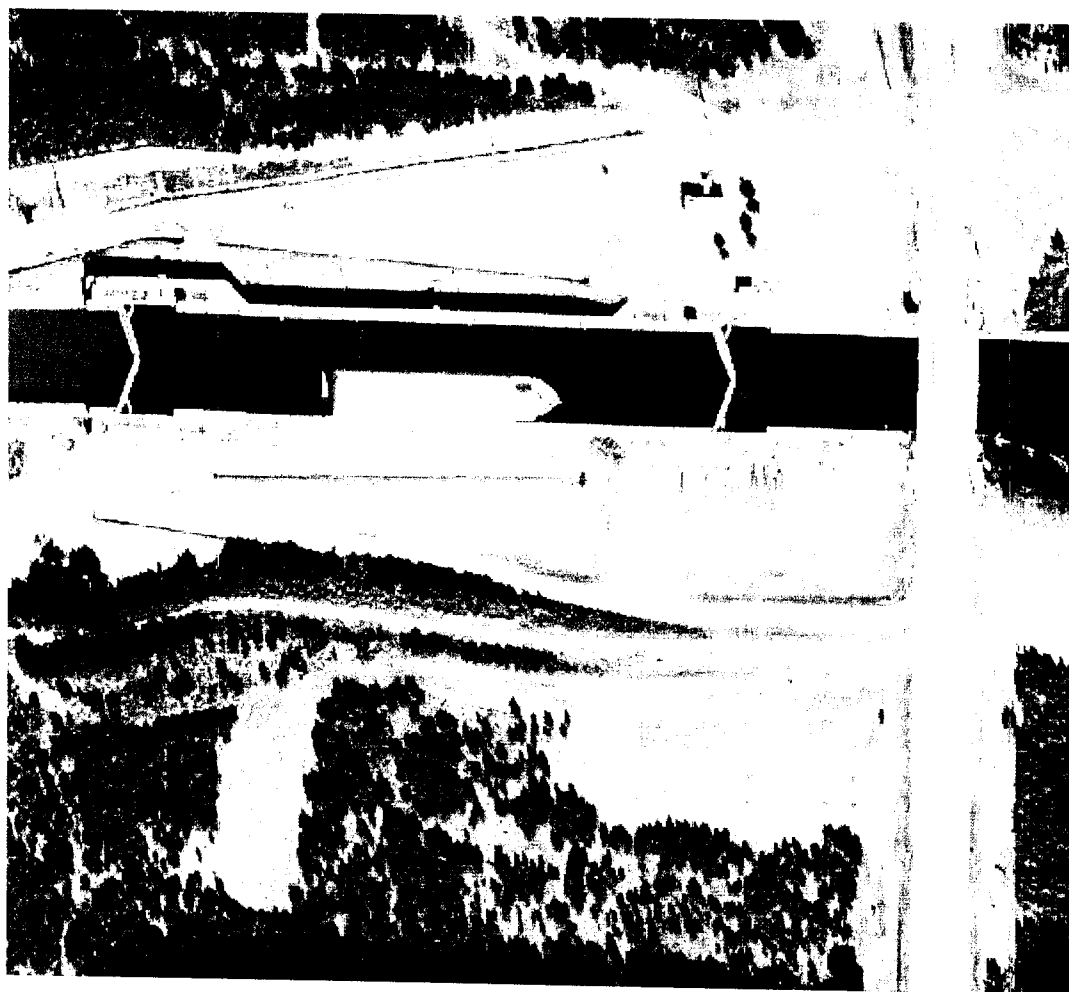Ph: 228-688-2305
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SSC Remote Sensing Radial Target and Edge Response Targets

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Drawbridge and River Lock at SSC

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Sample From Emerge
Product Tile

Road Intersection at SSC

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Emerge DSS
Geopositional Assessment Results

$(\Delta X)^2$ Sum	7.979 m	$(\Delta Y)^2$ Sum	6.894 m
$(\Delta X)^2$ Average	0.053 m	$(\Delta Y)^2$ Average	0.046 m
$RMSE_X$	0.23 m	$RMSE_Y$	0.214 m

RMSE Net	0.314 m
CE_{90}	0.476 m
CE_{95}	0.543 m

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(ΔX)^2 Sum	19.62 m	(ΔY)^2 Sum	16.76 m
(ΔX)^2 Average	0.12 m	(ΔY)^2 Average	0.11 m
RMSE$_X$	0.35 m	RMSE$_Y$	0.33 m

RMSE Net	0.48 m
CE$_{90}$	0.73 m
CE$_{95}$	0.83 m

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Significance of RER

RER also characterizes applicability of digital camera image products in quantitative remote sensing such as thematic mapping based on image classification.

- For such tasks, a digital raster image of Earth's surface is thought to divide the surface into a grid of square pixels with size of each pixel being equal to GSD.

- Radiance measured for each pixel is assumed to come from the Earth's surface area represented by that pixel.

- However, due to many factors, actual measurements integrate radiance from the entire surface with a weighting function provided by a system's point spread function (PSF).

- It can be shown that the Relative Edge Response squared (*RER*2) may be used to assess the percentage of the measured pixel radiance which actually originates from the Earth's surface area represented by the pixel.

RER References

- J.C. Leachtenauer, W. Malila, J.M. Irvine, L.P. Colburn, and N.L. Salvaggio, "General Image-Quality Equation: GIQE," Applied Optics, 36 (1997) 8322.

- "Multispectral Imagery Reference Guide," LOGICON Geodynamics, Fairfax, Virginia, 1997.

- See also:
  - http://www.fas.org/irp/imint/niirs_c/index.html
  - http://www.fas.org/irp/imint/niirs_ms/index.html